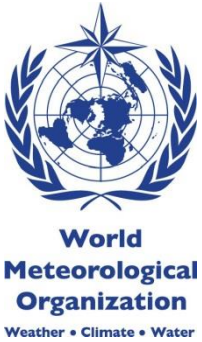
The dust cycle and impacts
Observation and prediction of airborne dust

Enric Terradellas, AEMET, Barcelona
WMO SDS-WAS. Regional Center for N. Africa, Middle East and Europe
Barcelona Dust Forecast Center



4t Training Course on WMO SDS-WAS Products
Casablanca, Morocco, 17-20 Nov 2014

Outline

- Atmospheric aerosol
- The dust cycle
- Observation of atmospheric dust
- Prediction of atmospheric dust

WMO SDS-WAS Regional Center for Northern Africa, Middle East and Europe

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AEMet Agencia Estatal de Meteorología
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación
World Meteorological Organization Weather • Climate • Water

Outline

- **Atmospheric aerosol**
- The dust cycle
- Observation of atmospheric dust
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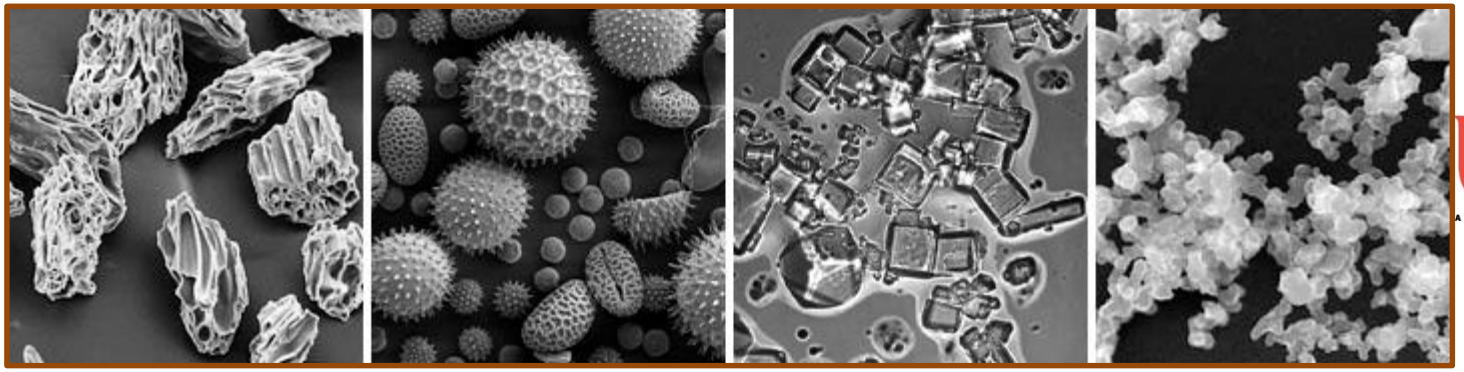
Atmospheric aerosol

Atmospheric aerosol

Solid or liquid particles suspended in the air

Particle size

Diameter ~ 0.002 – 100 µm



USGS science for a changing world

UMBC AN HONORS UNIVERSITY IN MARYLAND

ASU ARIZONA STATE UNIVERSITY

Aerosol sources

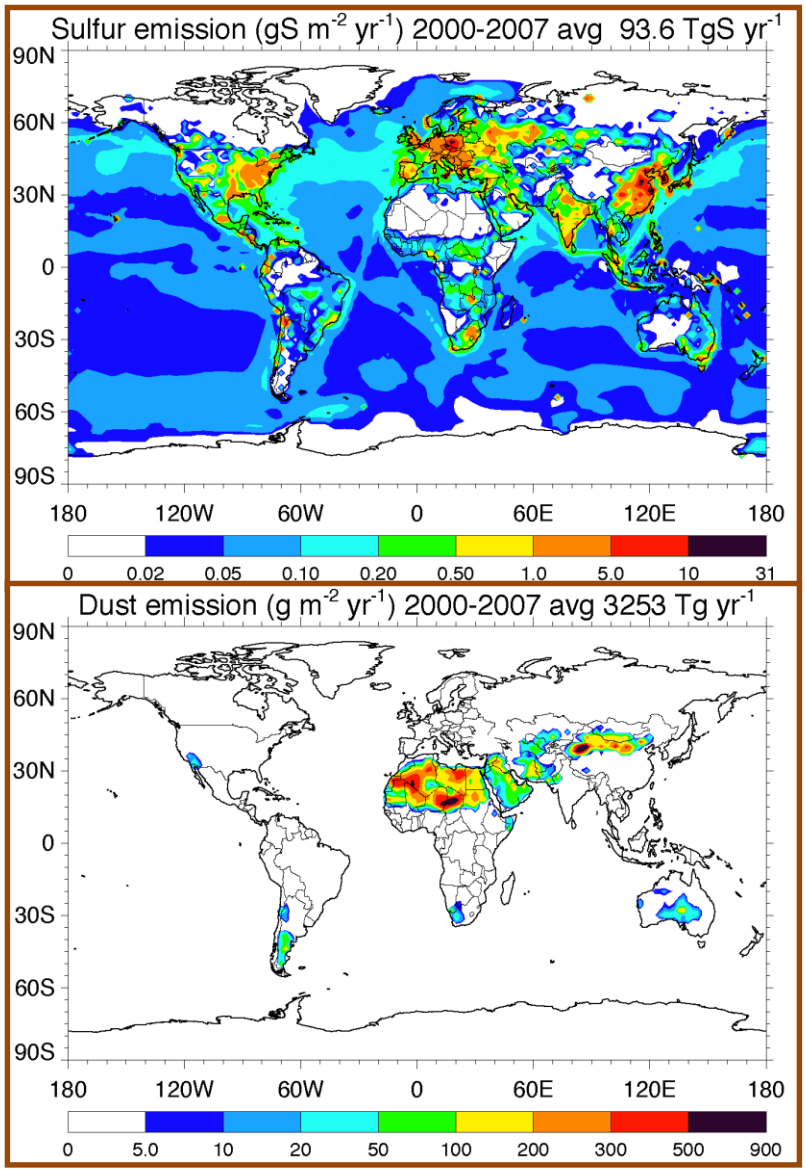


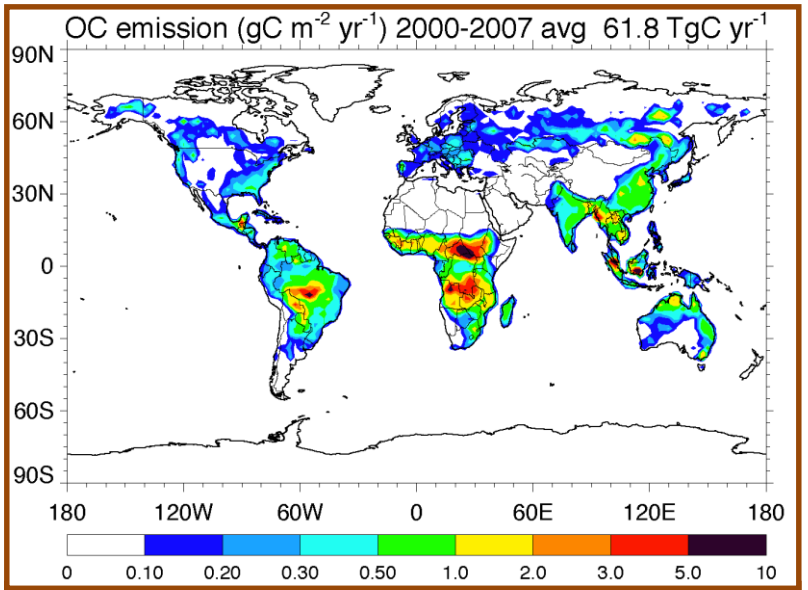


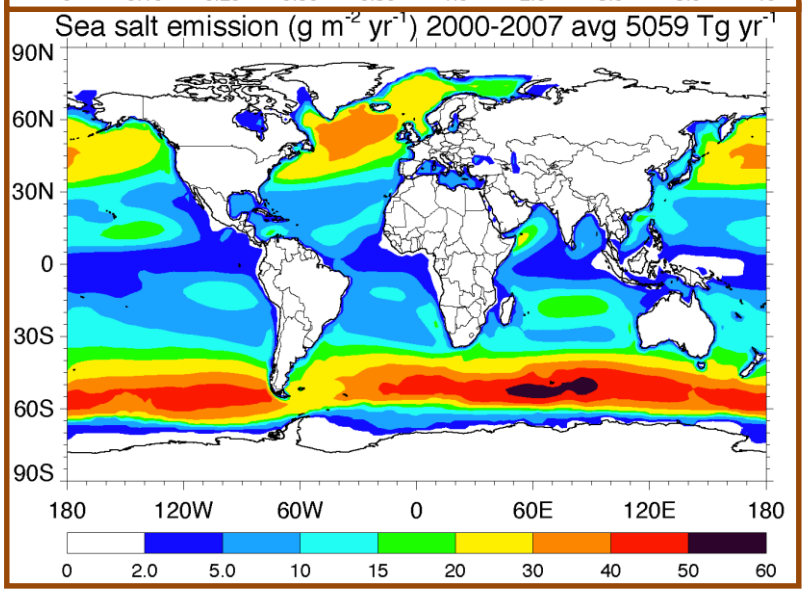

Volcanoes, botanical debris, sea salt, biomass burning, mineral dust, anthropic pollution, …

Atmospheric aerosol

Emissions 2000-2007







Chin et al. (2009)

- Atmospheric aerosol
- **The dust cycle**
- Observation of atmospheric dust
- Prediction of atmospheric dust

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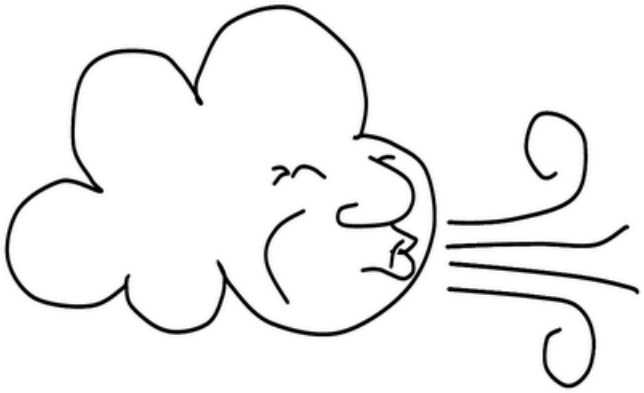
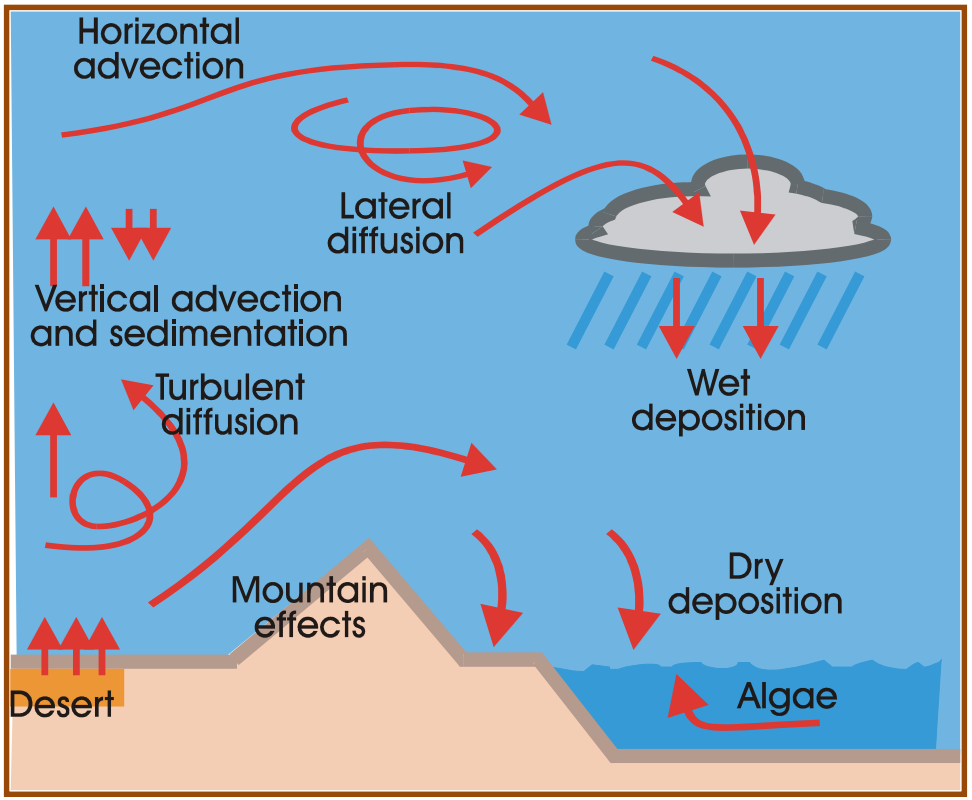
The dust cycle



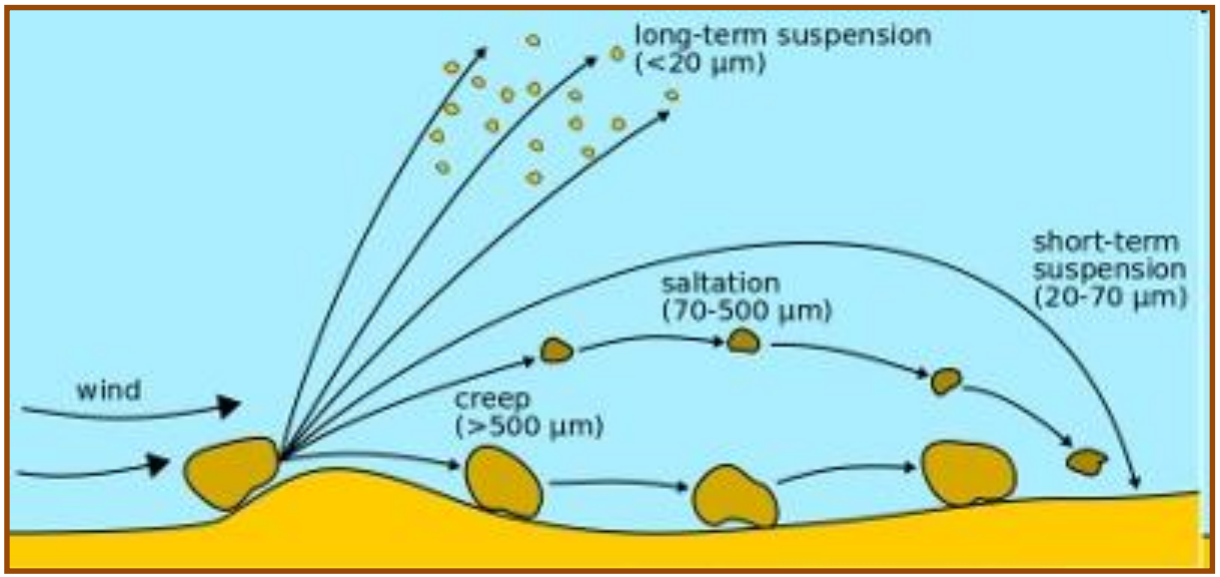
MODIS. 4 Feb 2013

The dust cycle



- **Emission**
- **Turbulent mixing**
- **Transport**
- **Dry/wet deposition**

Emission



Land factors

- **Soil texture**
- **Soil humidity**
- **Vegetation**

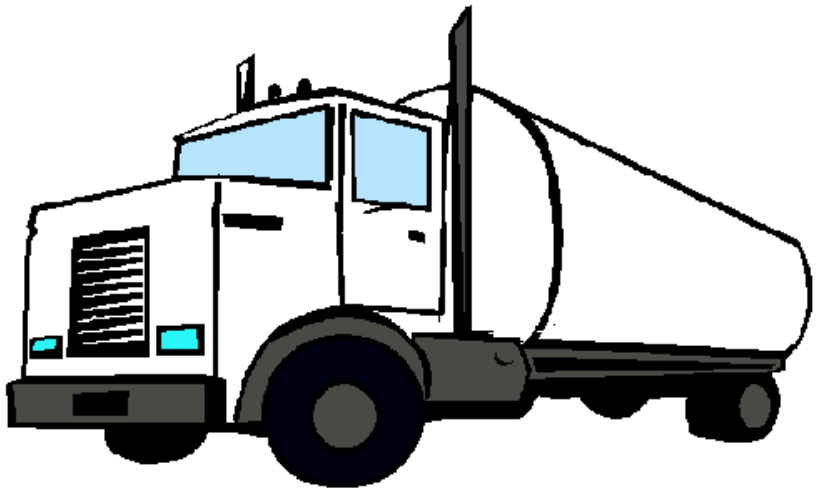
Meteorological factors

- **Wind**
- **Near-surface turbulence**

Mobilized dust

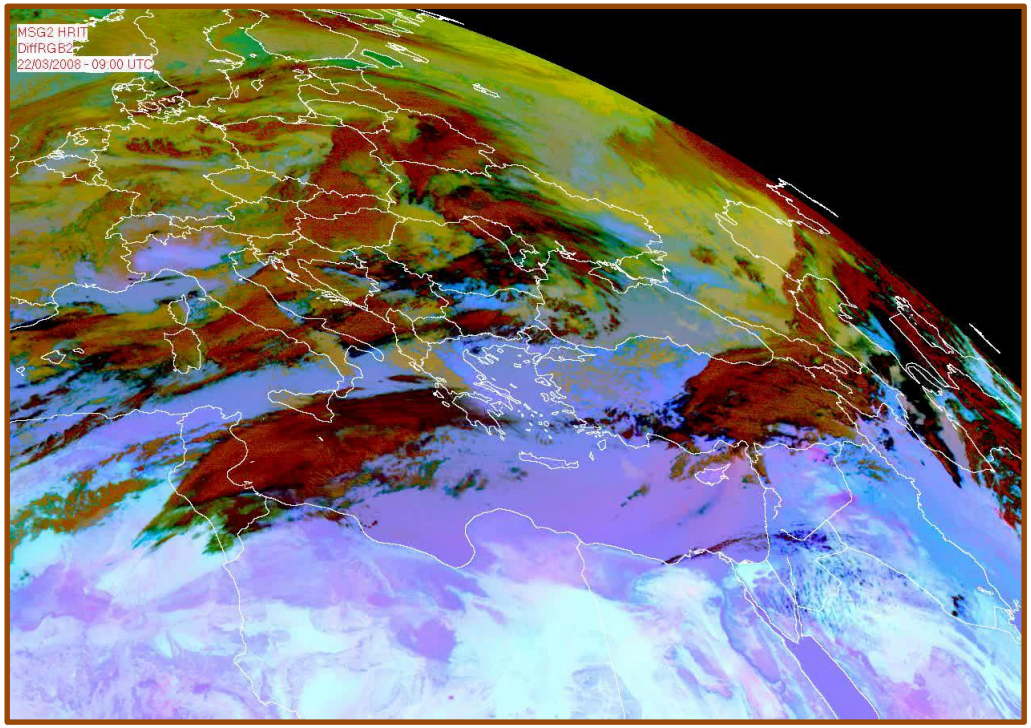
~ 30,000 – 60,000 kg / s
~ 1 – 3·10^{12} kg / yr

50,000,000 trucks



3,000 ULCC

Meteorological conditions

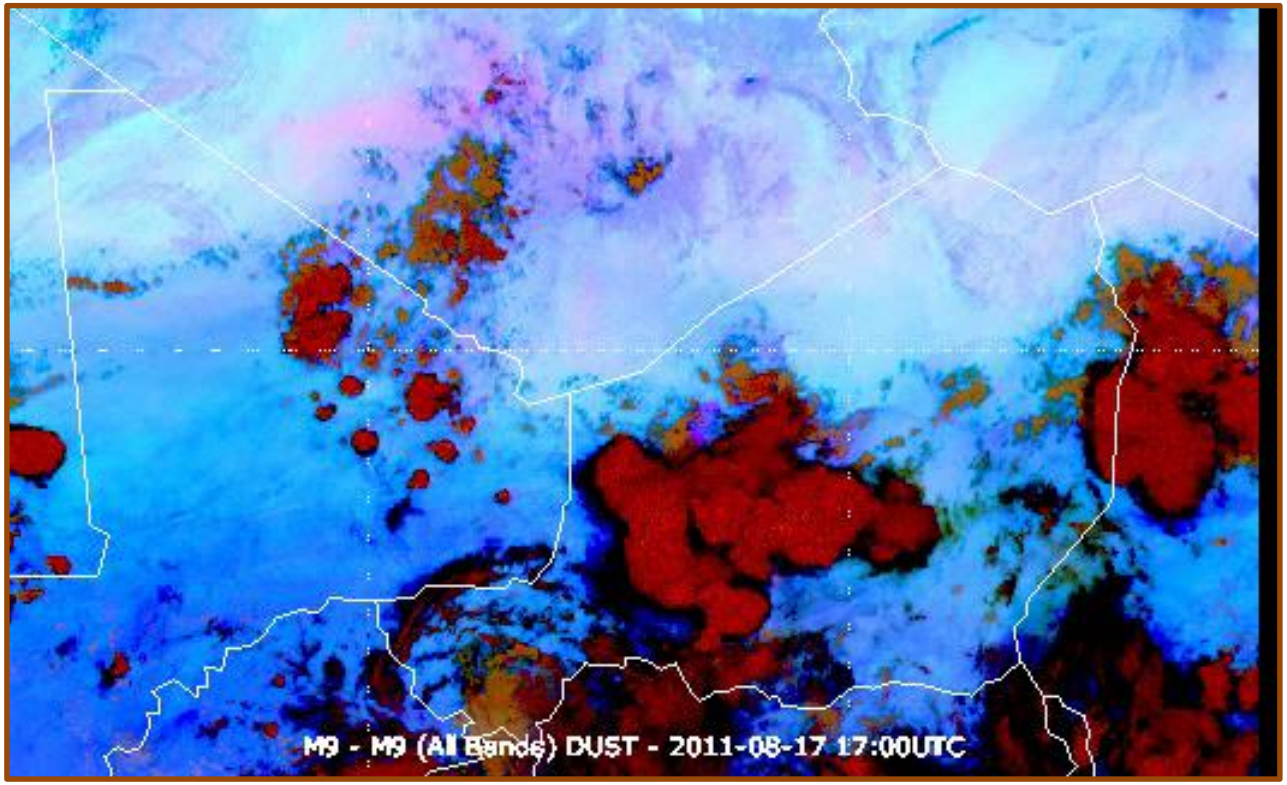


EUMETSAT

SYNOPTIC SCALE

- **Frontal systems**
- **Reinforced trade winds**

Meteorological conditions



EUMETSAT

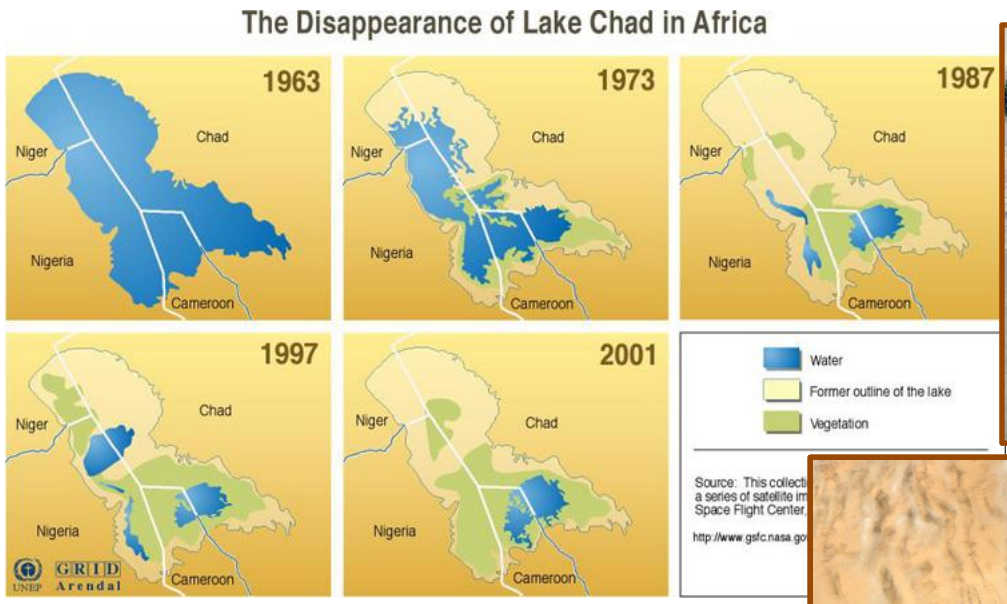
MESOSCALE-MICROSCALE

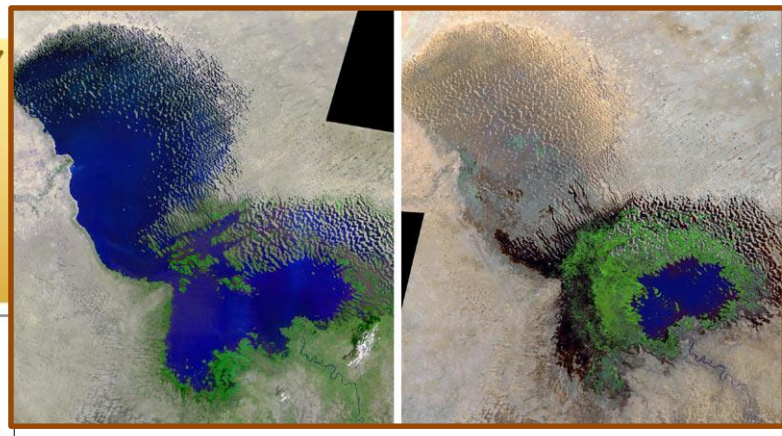
Convection	Drainage winds
Low-level jets	Gap winds

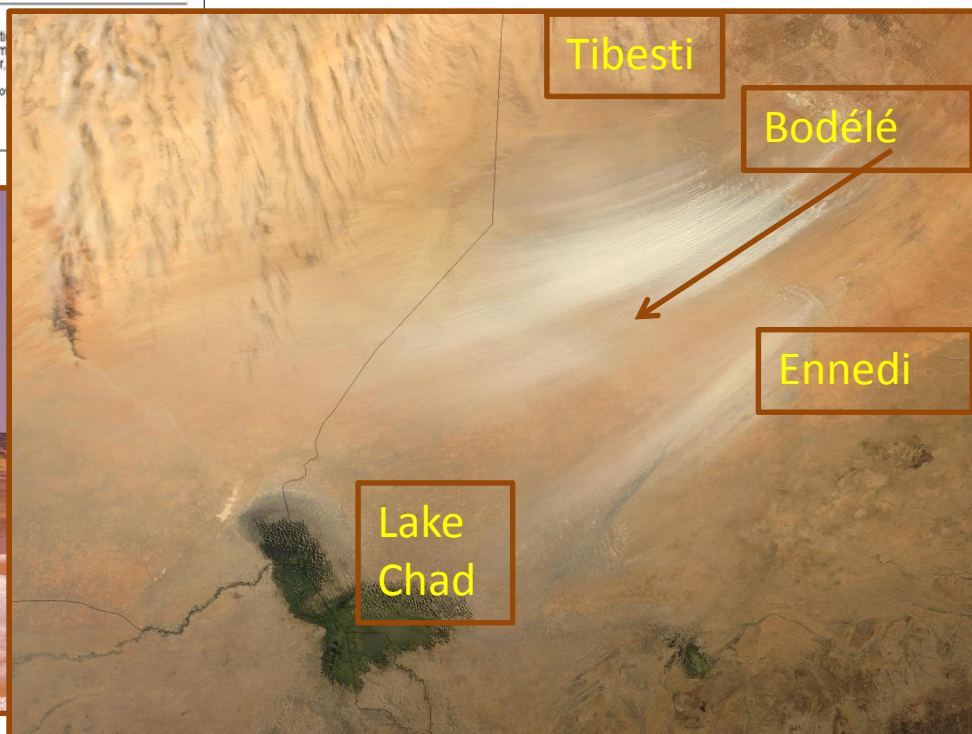
Dust sources

The dust cycle

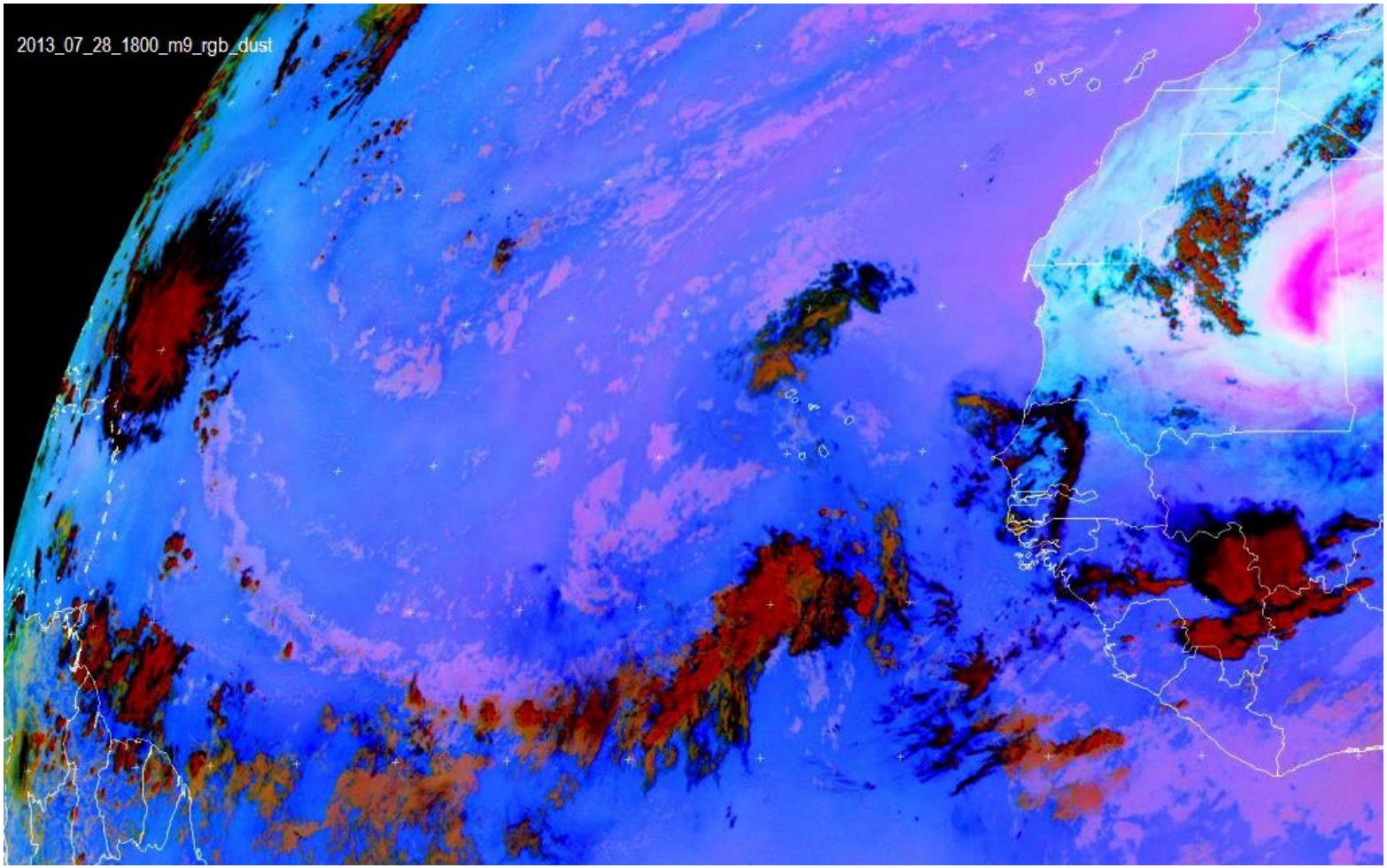
The Bodélé depression





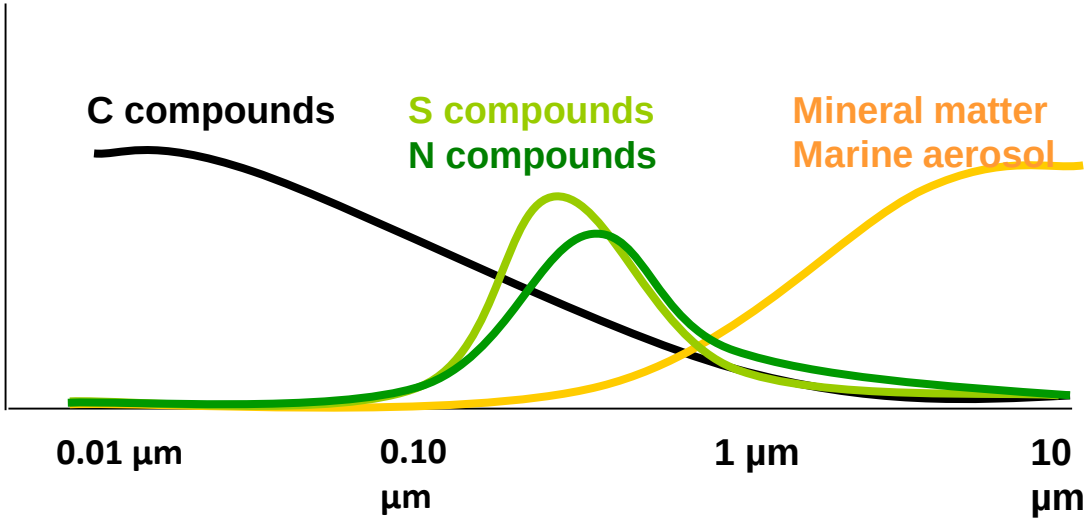


Transport

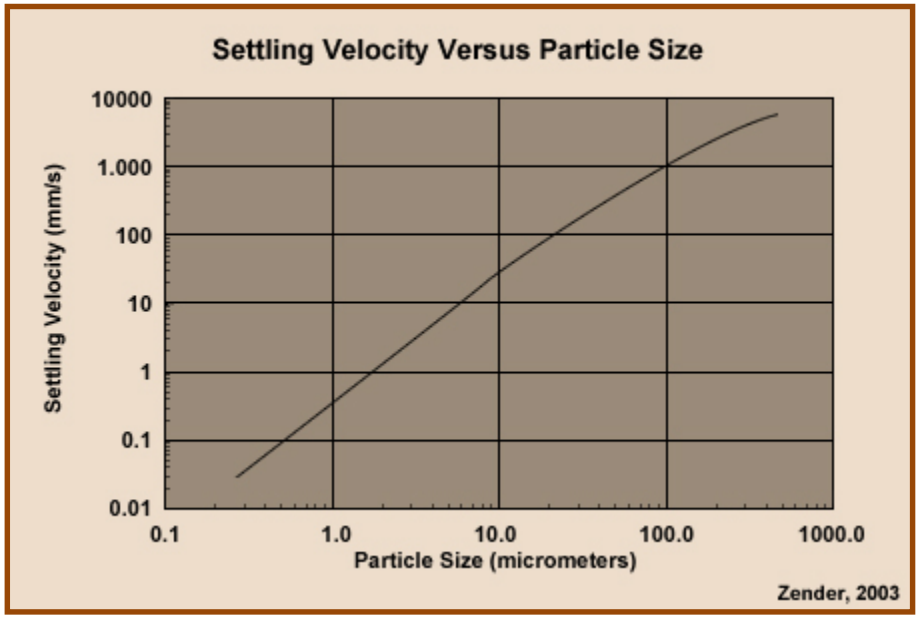


Thunderstorms over W Africa arise large amounts of dust. On 30 July 2013, dust starts crossing the Atlantic and reaches the Antiles on 2 August

Dry deposition



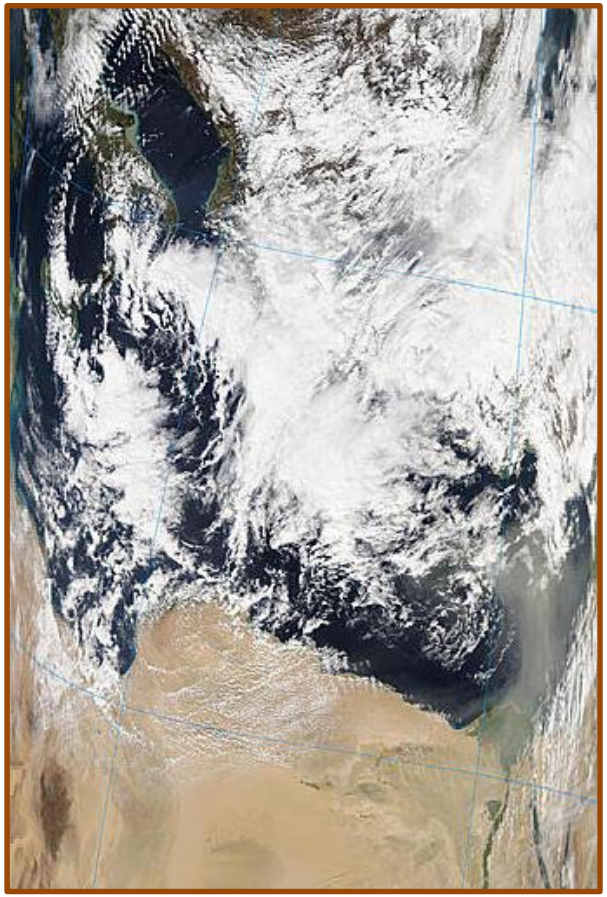
Warneck (1988), Harrison and Van Grieken (1998)



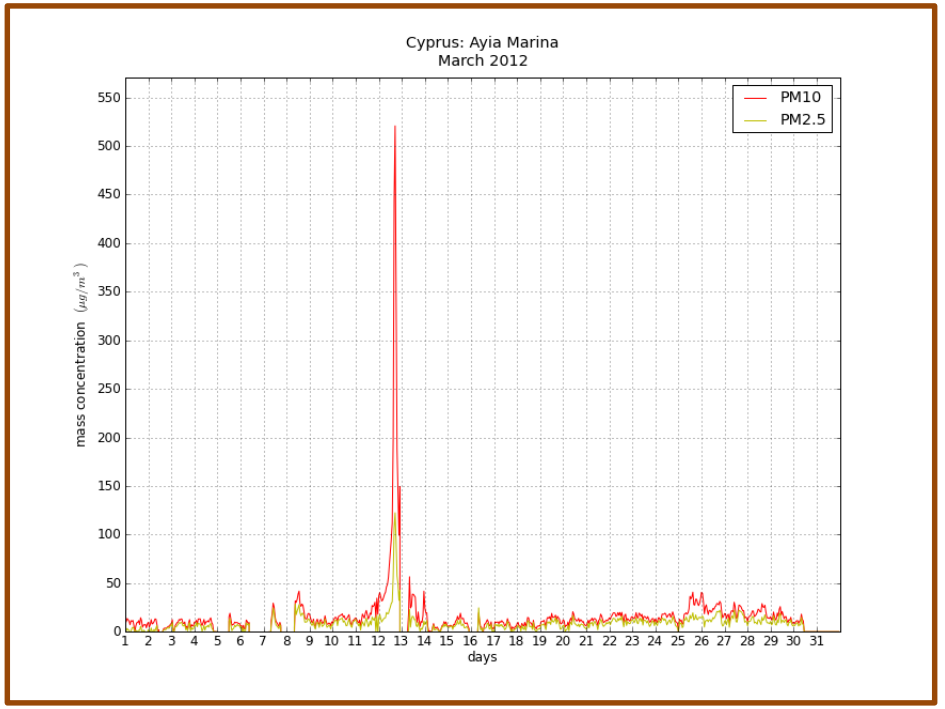
SIZE (µm)	AVERAGE LIFETIME (h)
0.1 - 0.18	231
0.18 - 0.3	229
0.3 - 0.6	225
0.6 – 1	219
1 - 1.8	179
1.8 – 3	126
3 – 6	67
6 - 10	28

Tegen and Lacis (1996)

Wet deposition



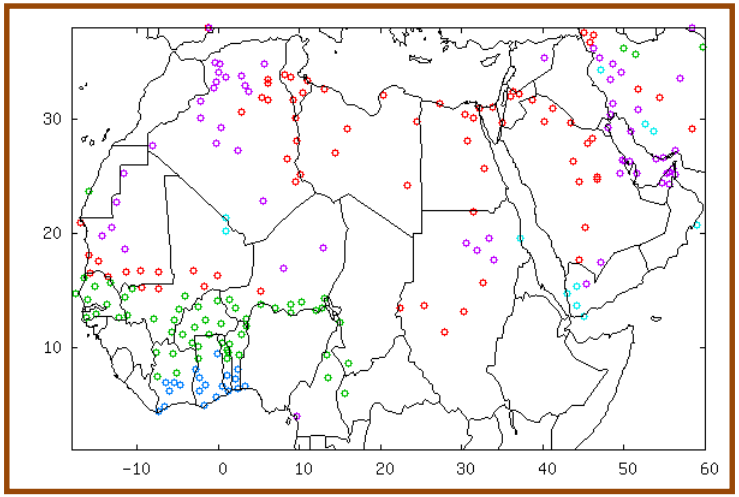
MODIS 12 Mar 2012

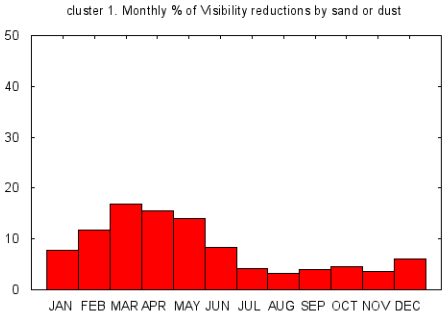


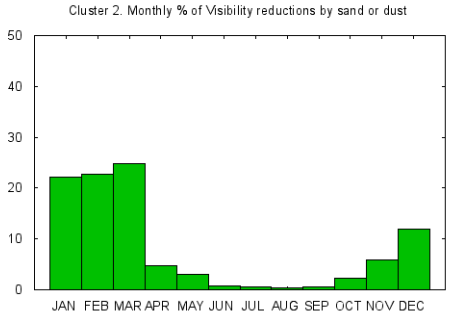
Ayia Marina (Cyprus)
March 2012

The dust cycle

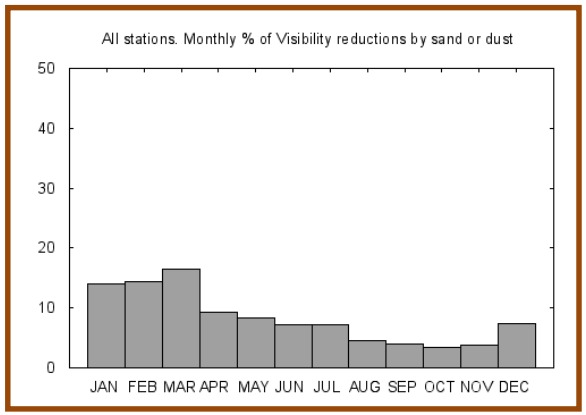
Seasonal variability

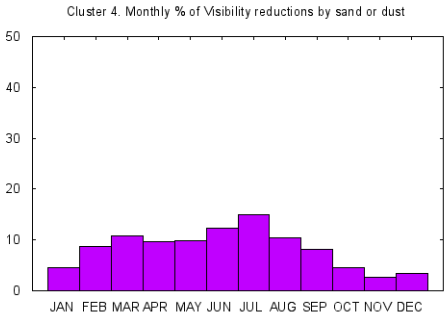


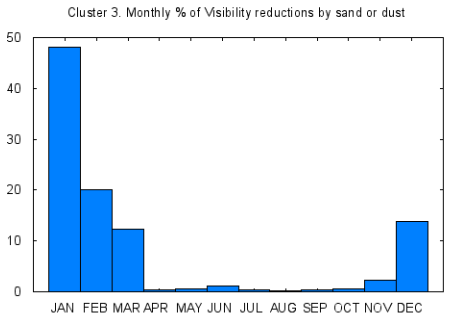


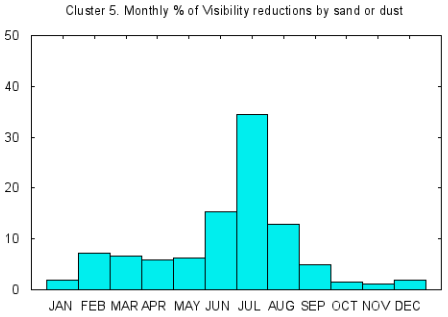


1996-2010









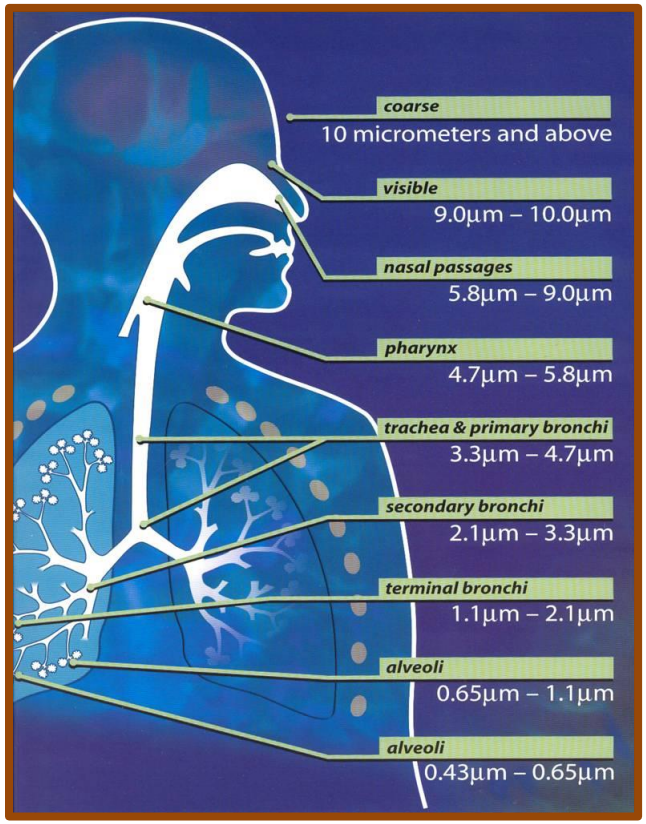
Terradellas et al. (2012)

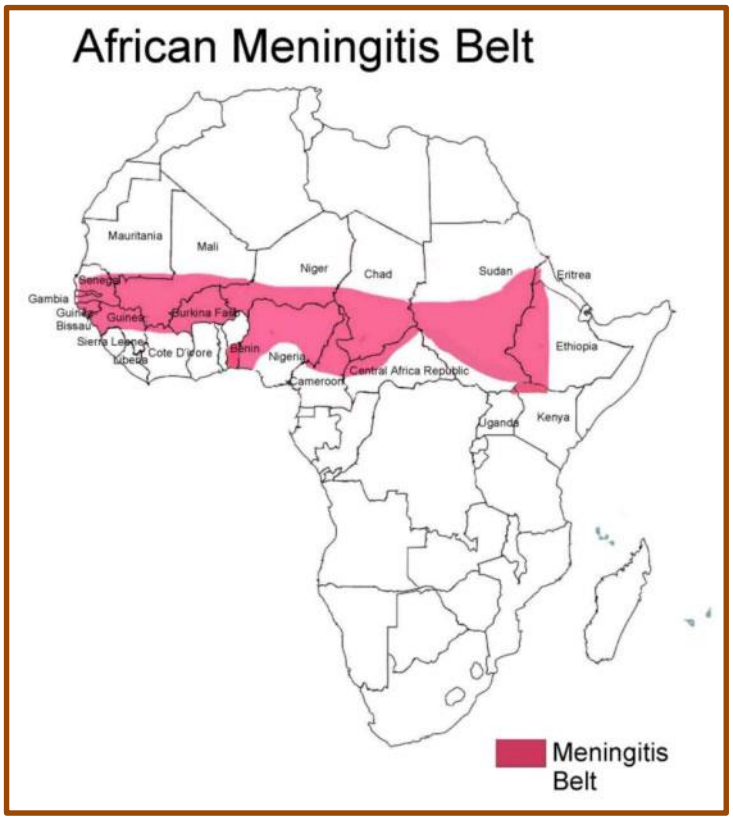
Impacts of atmospheric dust

- Health
- Weather and climate
- Transport (visibility reduction)
- Energy generation
- Agriculture, forestry, fishing
- …

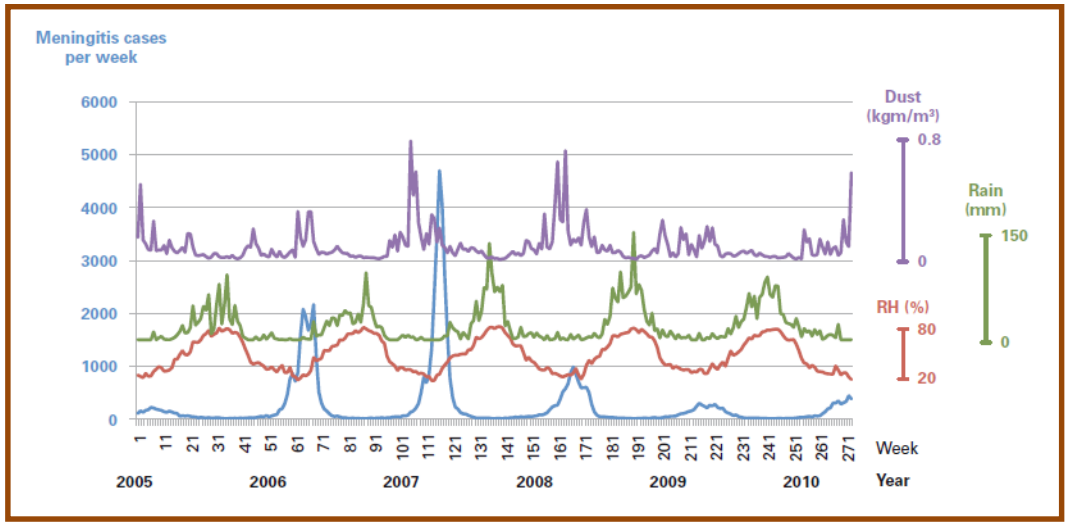
The dust cycle

Health





Burkina Faso

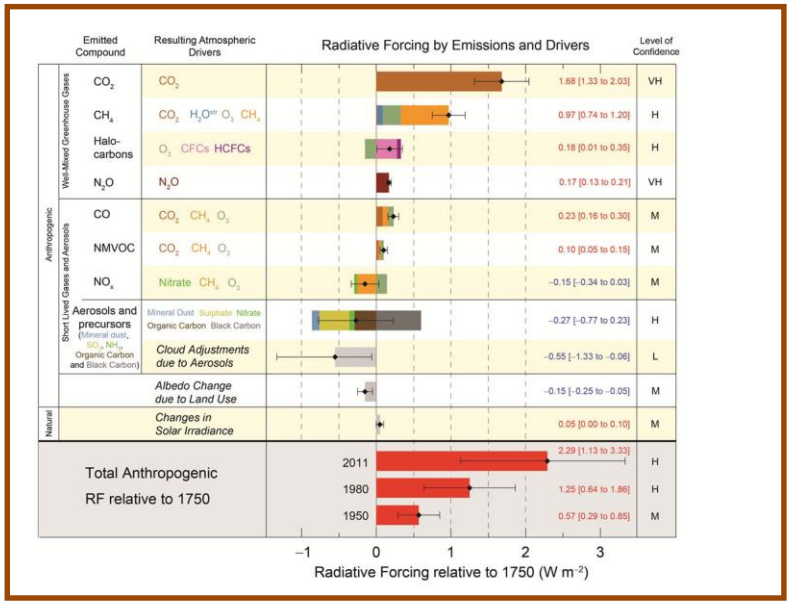


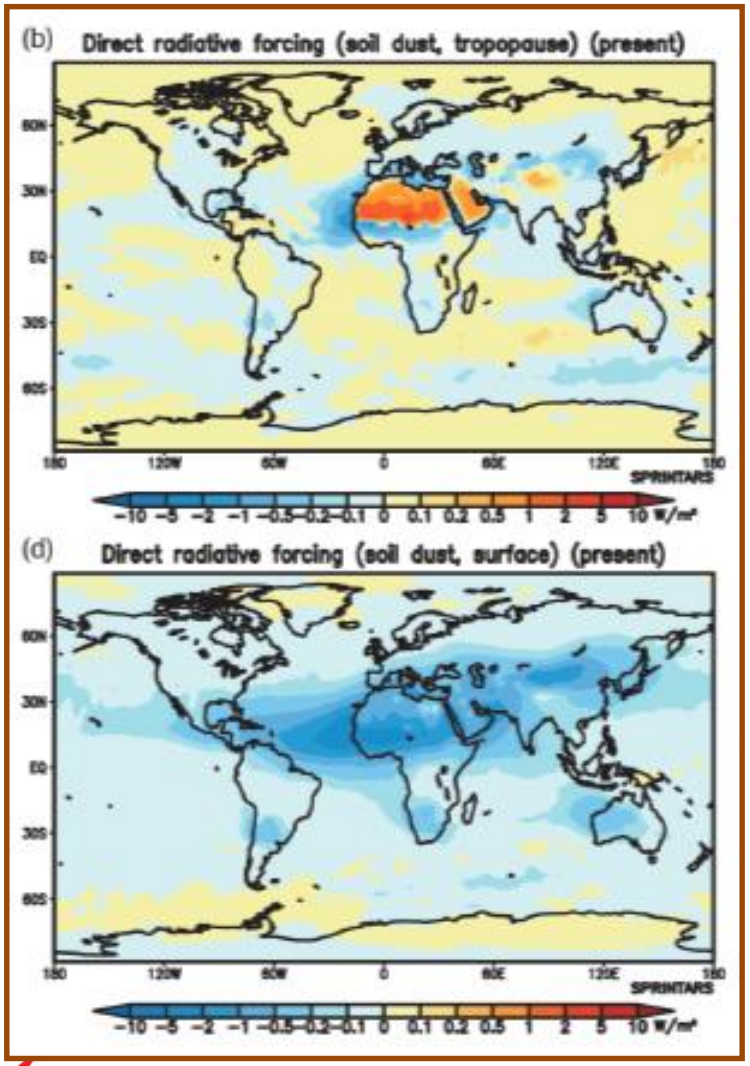
World Health Organization

World Meteorological Organization
Weather · Climate · Water

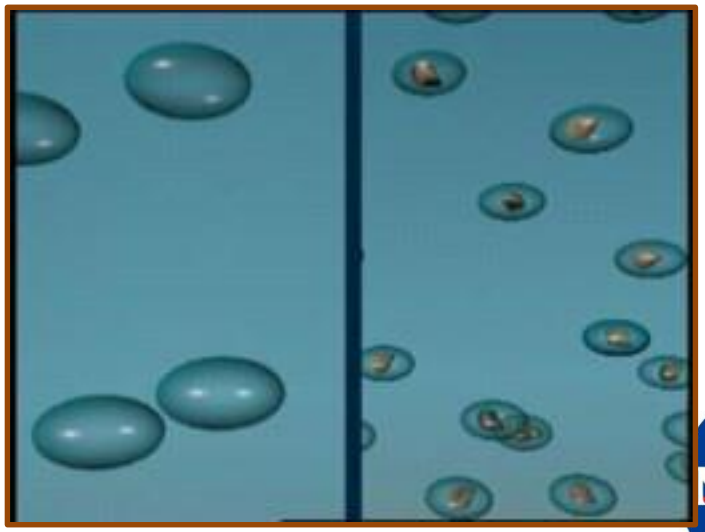
Weather and climate

The dust cycle



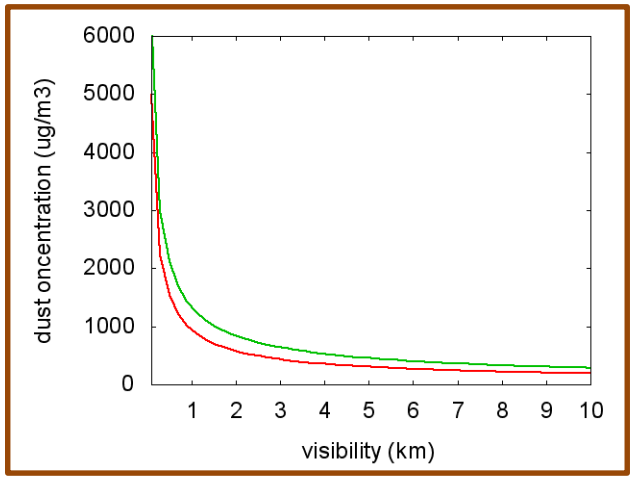


Takemura et al. (2009)



NASA

Transport

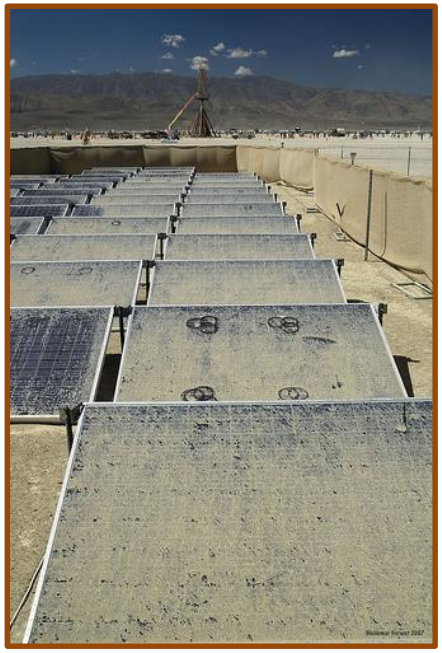


D'Almeida (1986)

Ben Mohamed et al. (1992)

Generation of solar energy

- **Reduction of the available energy**
- **Reduction of the efficiency**



Agriculture – Forestry - Fishing

WMO SDS-WAS

Mission:

Improve the capacity of countries to produce and distribute to end users accurate forecasts of the mineral dust content in the atmosphere

Structure:

- Regional Center for Northern Africa, Middle East and Europe. Barcelona, Spain
- Regional Center for Asia, Beijing, China
- Regional Center for Pan America, Univ. Arizona, U.S.A.
- Regional Center for West Asia (??)

Regional Center NA-ME-E

The Center is managed by a consortium of AEMET and the Barcelona Supercomputing Center (BSC-CNS)

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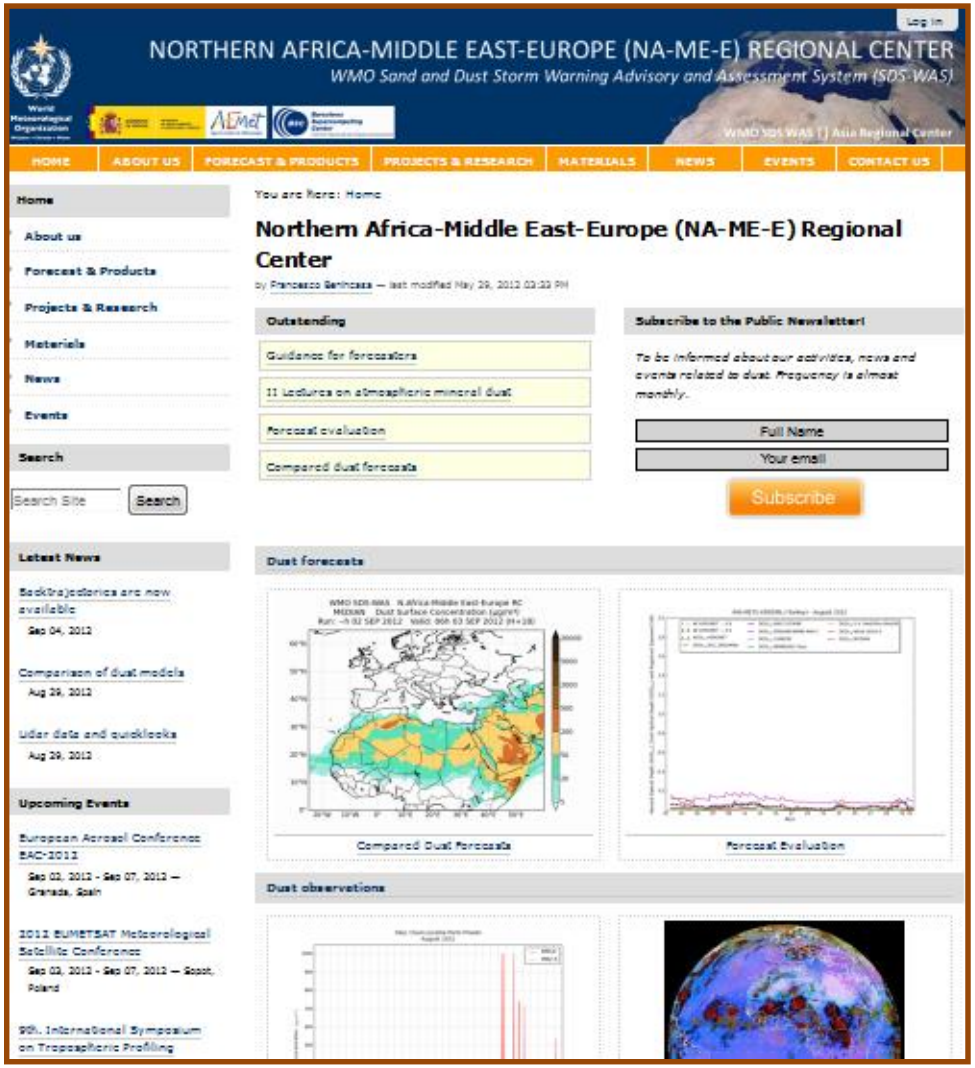
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

Nexus II Building. Barcelona

MareNostrum – 3 supercomputer

The dust cycle

http://sds-was.aemet.es



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Operational forecasts

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AEMet Agencia Estatal de Meteorología

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

May 2013. The WMO designates the consortium of AEMET and the BSC to host the first Regional Specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecast (RSMC-ASDF). The Center shall operationally generate and distribute dust predictions for Northern Africa, Middle East and Europe.

Feb 2014. The Barcelona Dust Forecast Center (BDFC) is created to be this RSMC-ASDF

Jun 2014. The BDFC is publicly presented

http://dust.aemet.es

dust@aemet.es eterradellasj@aemet.es

- Atmospheric aerosol
- The dust cycle
- **Observation of atmospheric dust**
- Prediction of atmospheric dust

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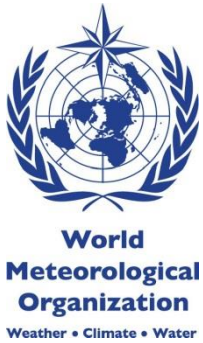


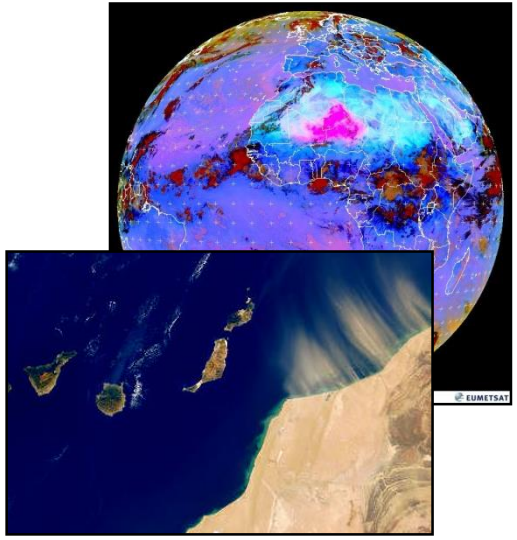
Why do we need dust observations?

- **Dust monitoring**
- **Evaluation of numerical dust forecasts**
- **Data assimilation into dust models**
- **Validation of other observations (i. e. ground observations to validate satellite products)**

Mali, 2001
Photo: Remi Benali/Corbis

A comprehensive observing system

- Ground observations
  - In-situ
  - Indirect obs.: visibility
  - Sun photometers
  - Lidar – ceilometers
- Satellite observations



AQ station

Transmissometer

In-situ measurements of PM10 and PM2.5 in AQ monitoring stations

W_1

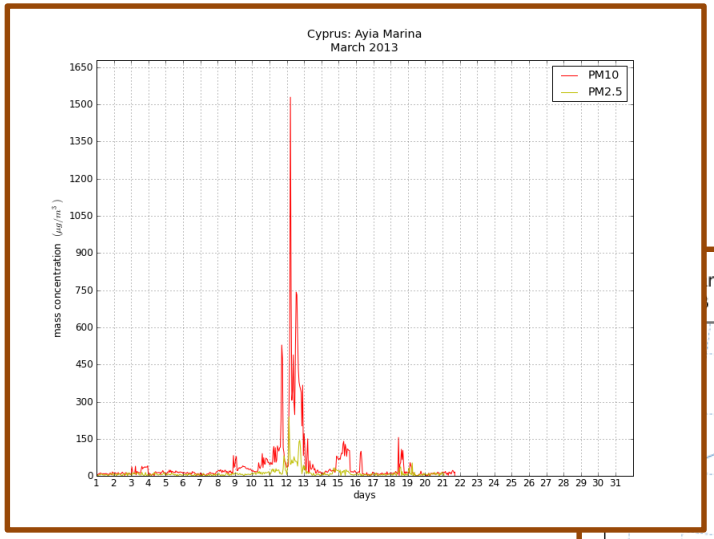
W_2

$$PM = \frac{(W2-W1)}{Volumen} \ \mu g/m^3$$

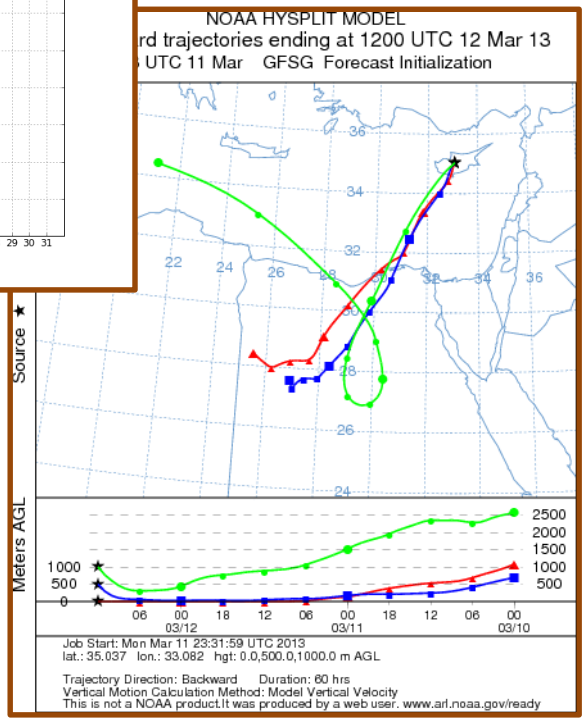
Monitoring dust events with in-situ observations

Observation of atmospheric dust

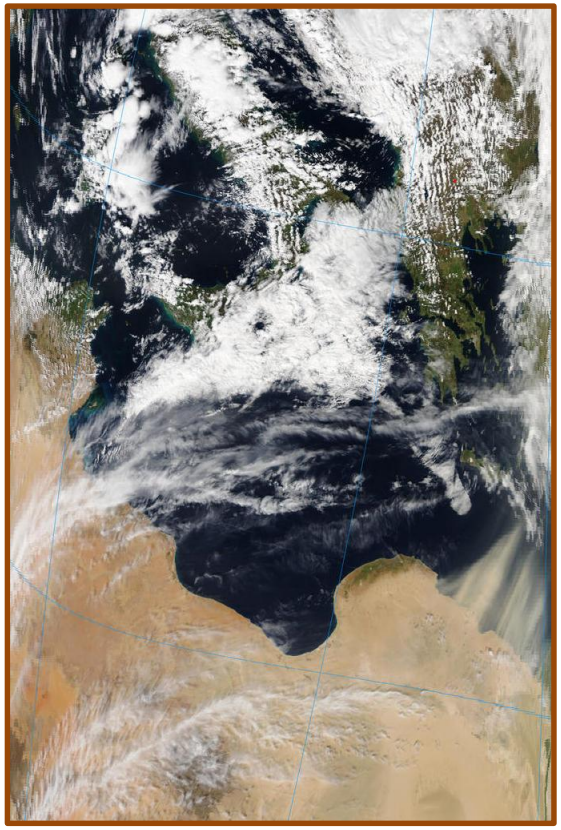
Monitoring dust events with in-situ observations



Mar 2013



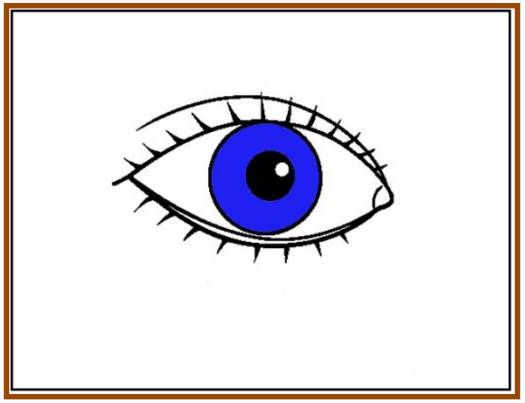
12 Mar 2013

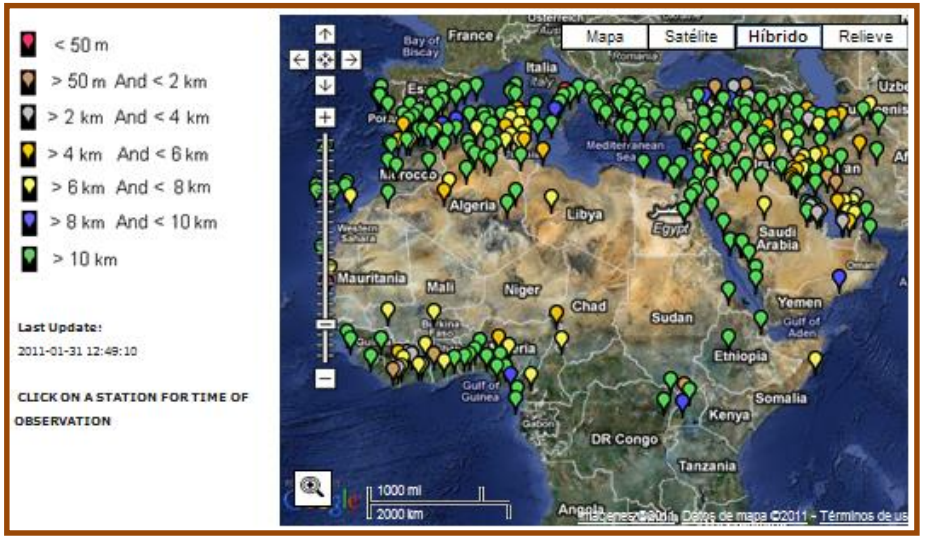


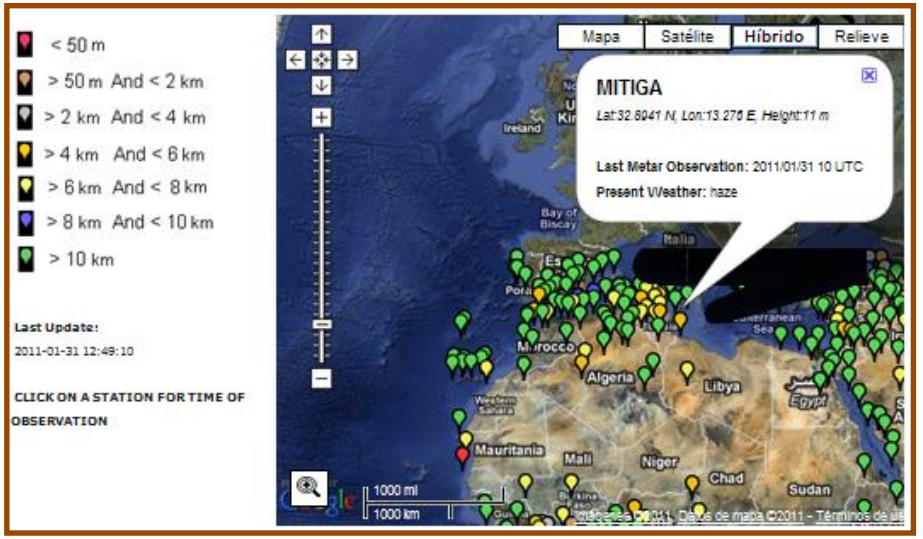
11 Mar 2013

Observation of atmospheric dust

Visibility and present weather from meteorological reports

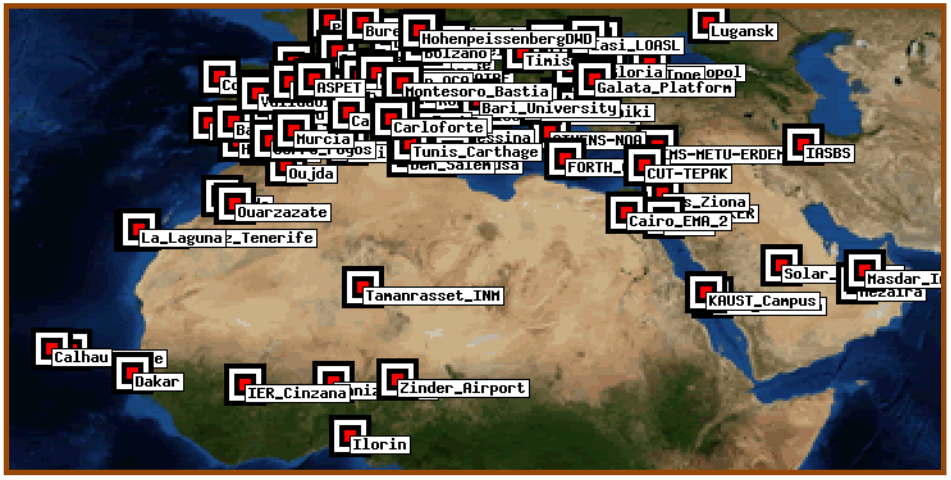






BSC **Barcelona Supercomputing Center**
Centro Nacional de Supercomputación

Sun photometers



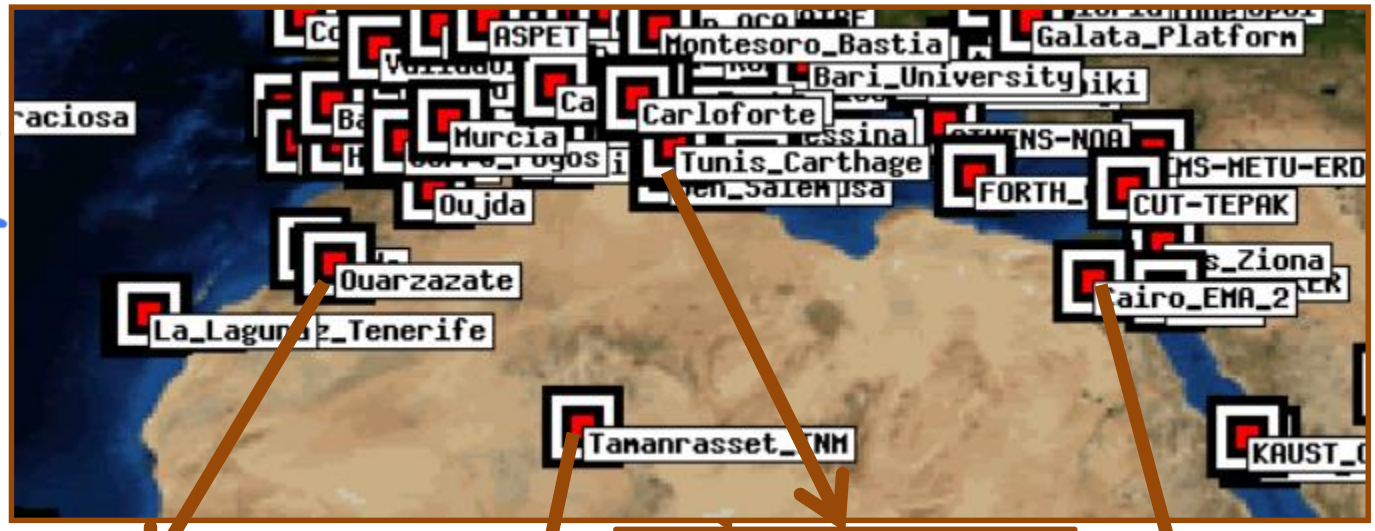
- **Sun photometers measure direct solar radiation**
- **Radiation at the top of the atmosphere is known**
- **Particles dissipate energy due to absorption and scattering**
- **Information on the aerosol concentration can be derived from the radiation that reaches the Earth surface**

Observation of atmospheric dust

SDS-Africa

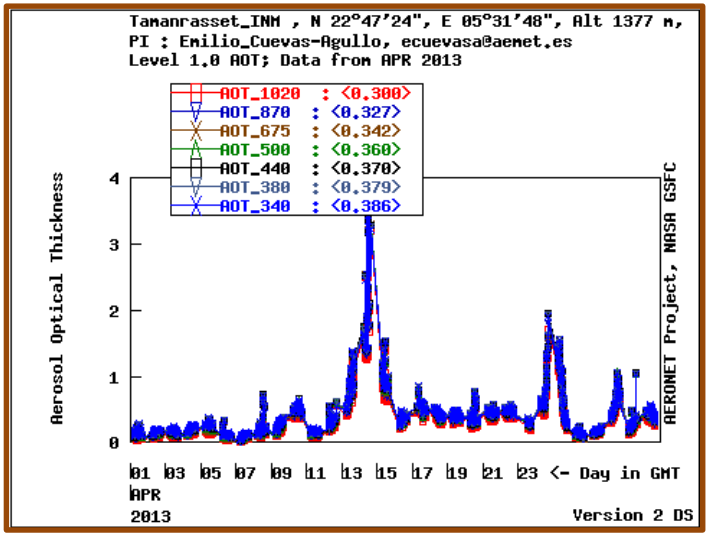
AGENCIA ESPAÑOLA DE COOPERACIÓN INTERNACIONAL

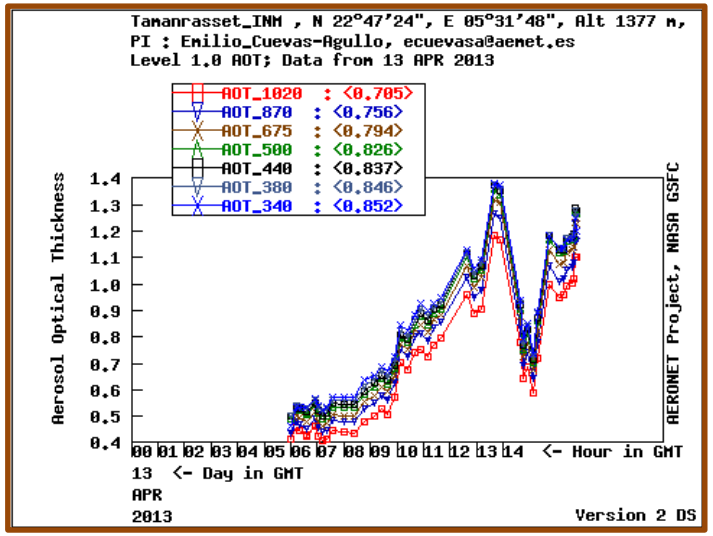
AEMet
Agencia Estatal de Meteorología

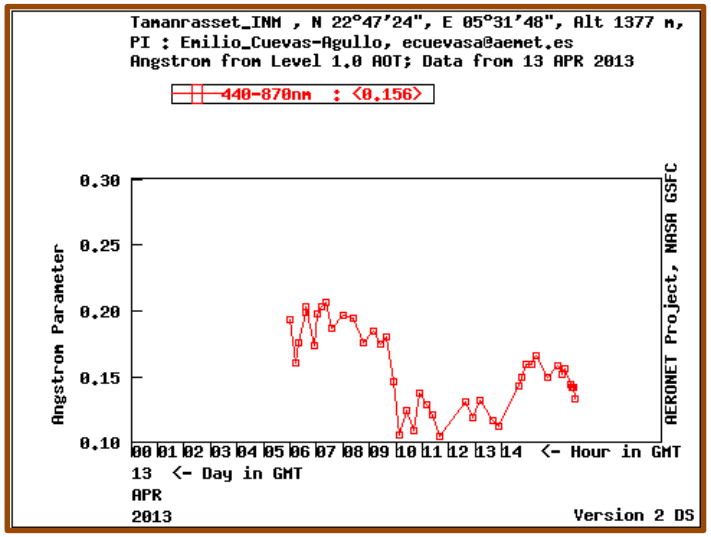


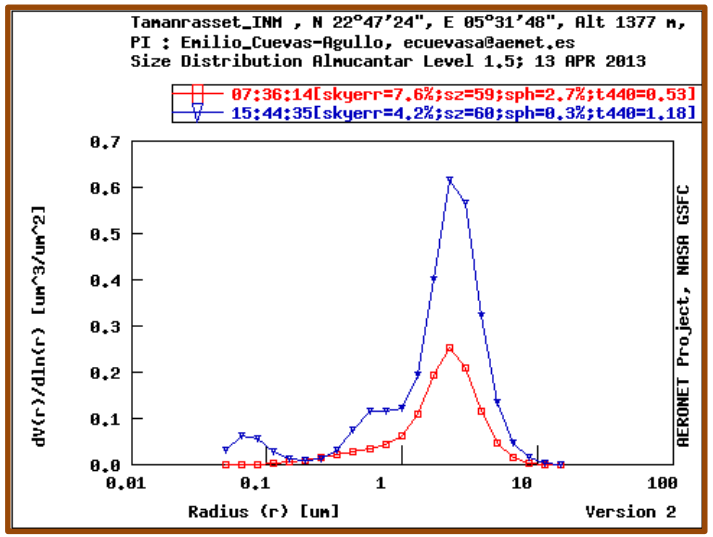
Observation of atmospheric dust

Monitoring dust events with AERONET data





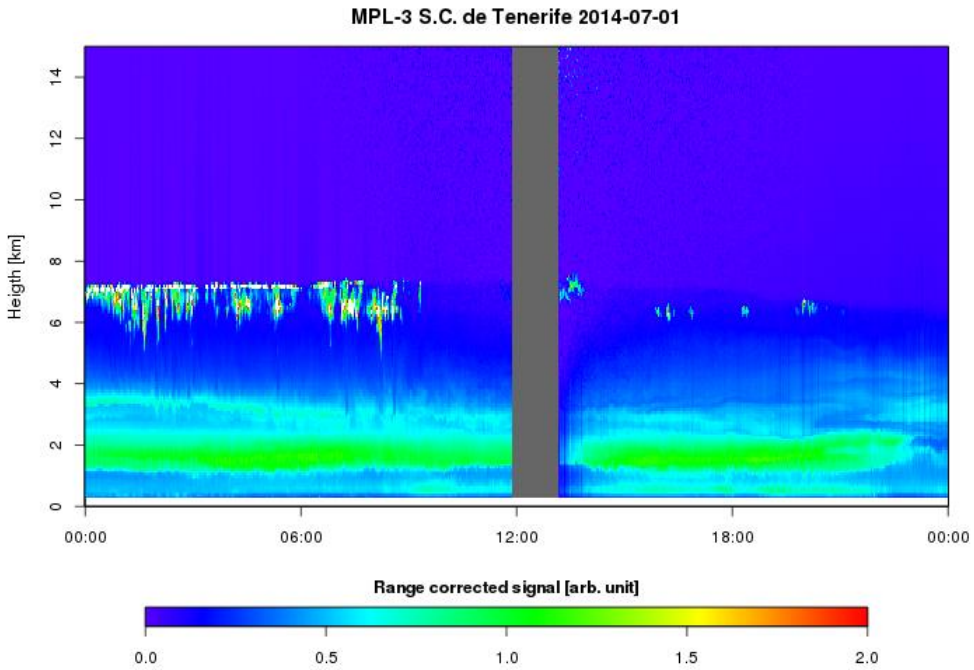


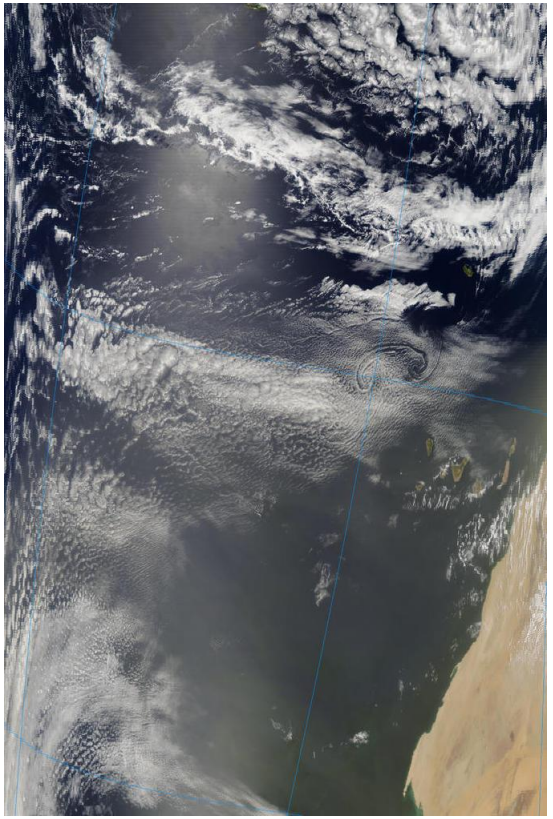


Tamanrasset, Algeria, 13 Apr 2013

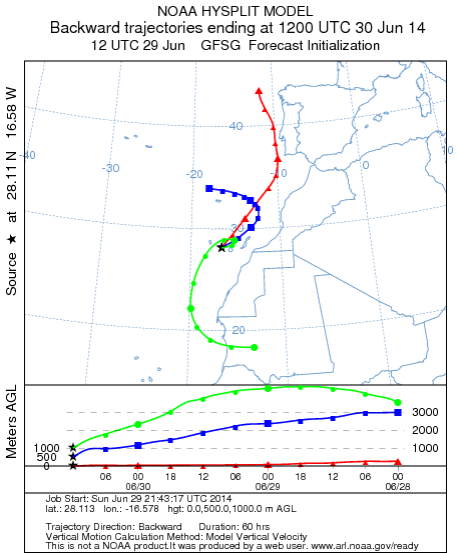
Observation of atmospheric dust

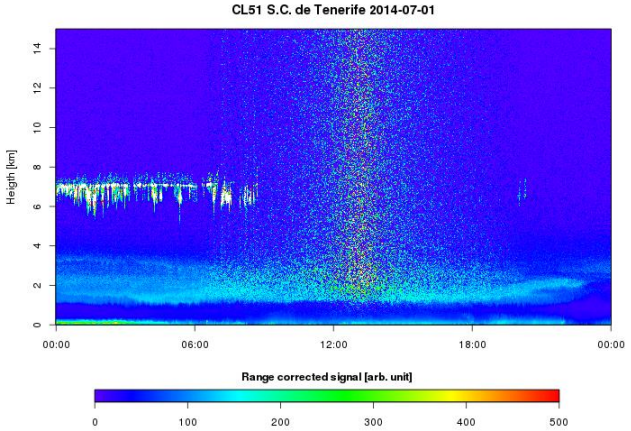
Lidar





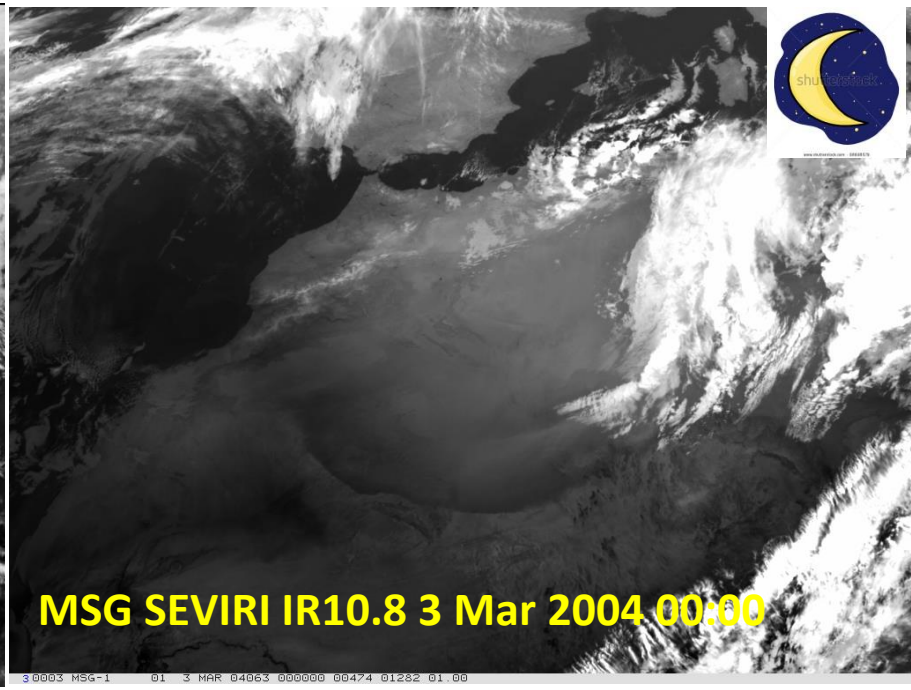
Santa Cruz de Tenerife, 1 Jul 2014

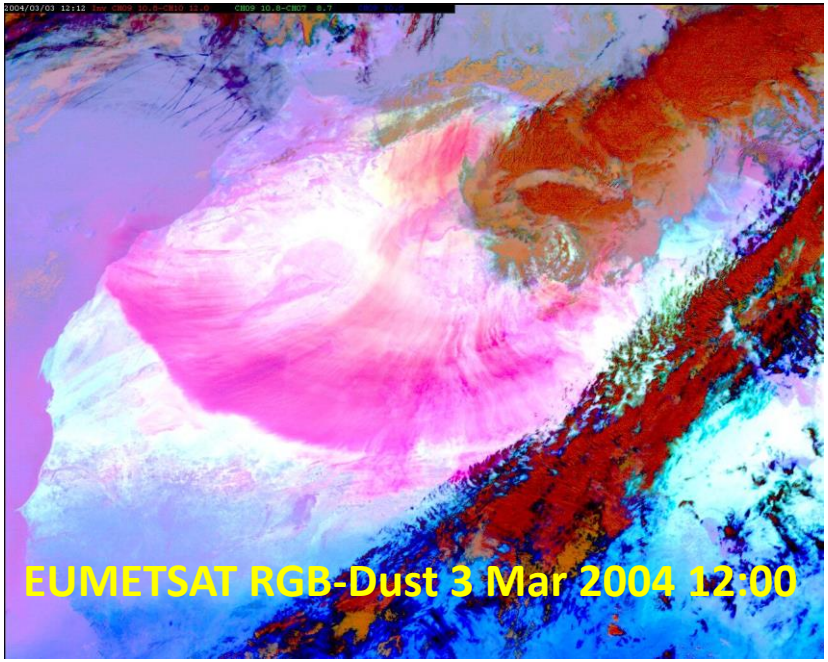


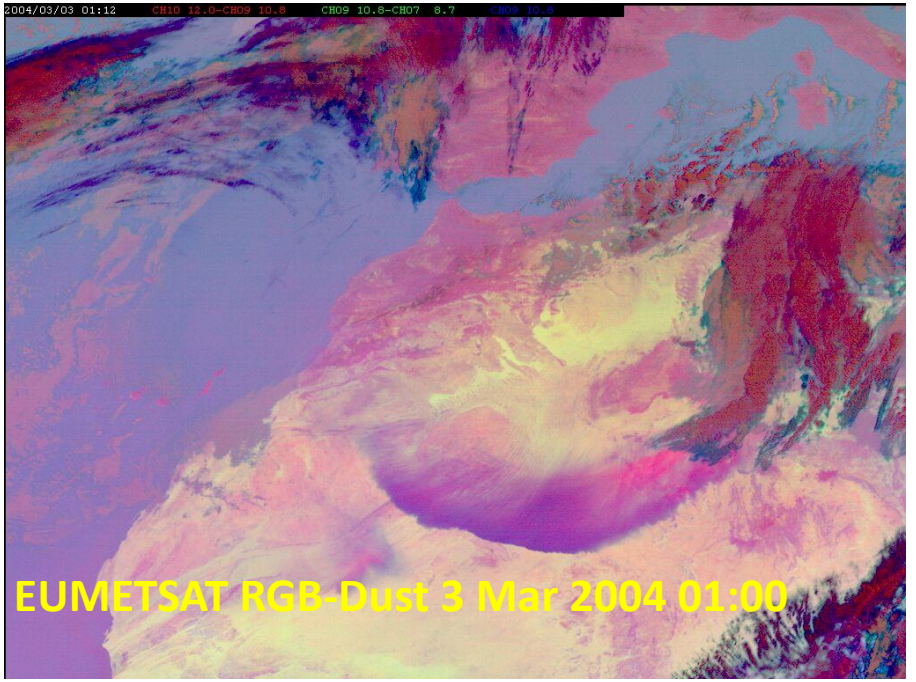


Observation of atmospheric dust

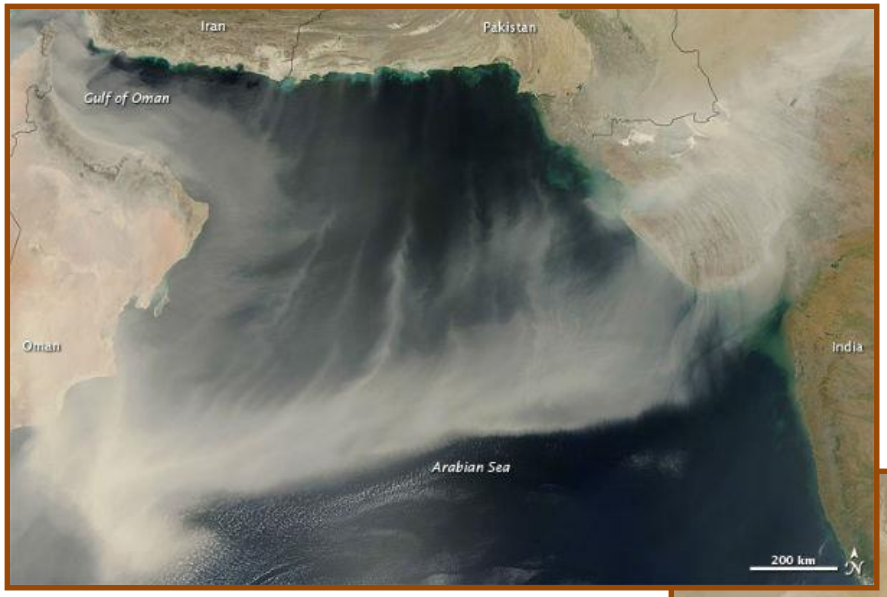
IR / RGB-Dust







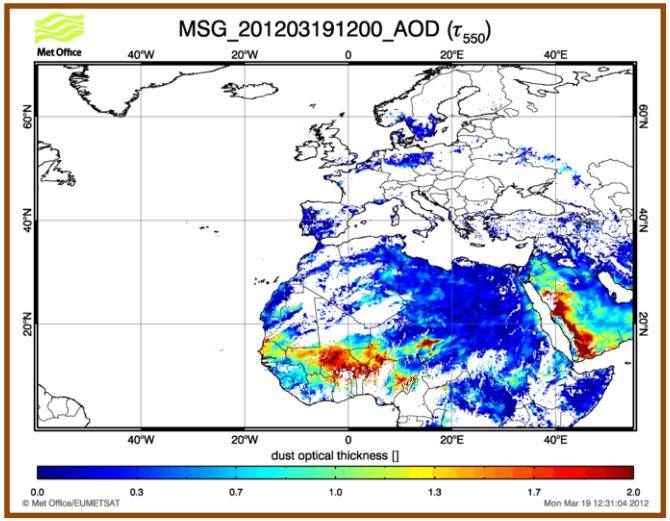
Other composites: MODIS

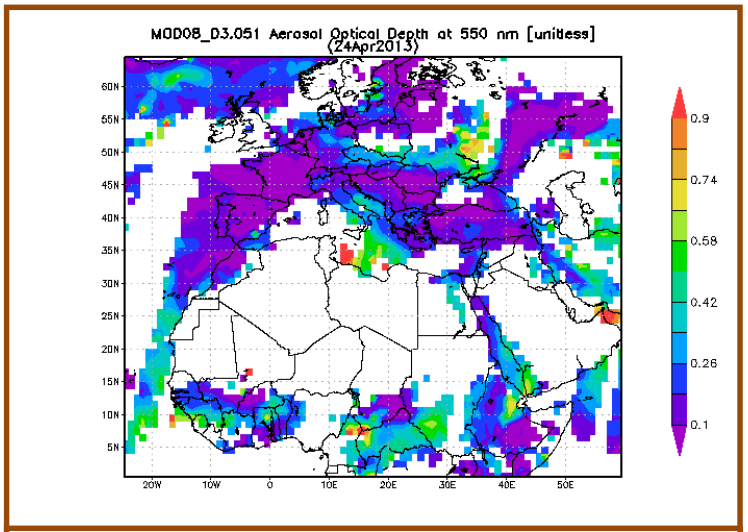


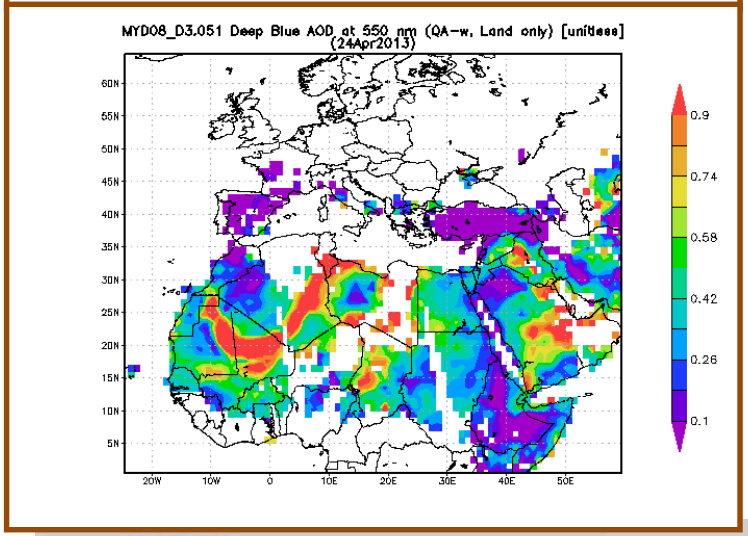
Observation of atmospheric dust

Quantitative estimations of AOD

Met Office







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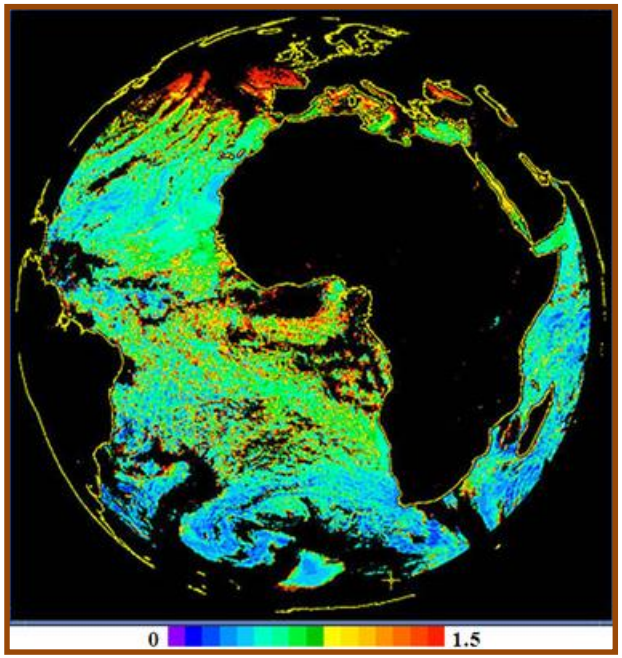

NASA GODDARD SPACE FLIGHT CENTER

Prediction of atmospheric dust

- Atmospheric aerosol
- The dust cycle
- Observation of atmospheric dust
- **Prediction of atmospheric dust**

WMO SDS-WAS Regional Center for Northern Africa, Middle East and Europe

http://sds-was.aemet.es

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Barcelona Dust Forecast Center

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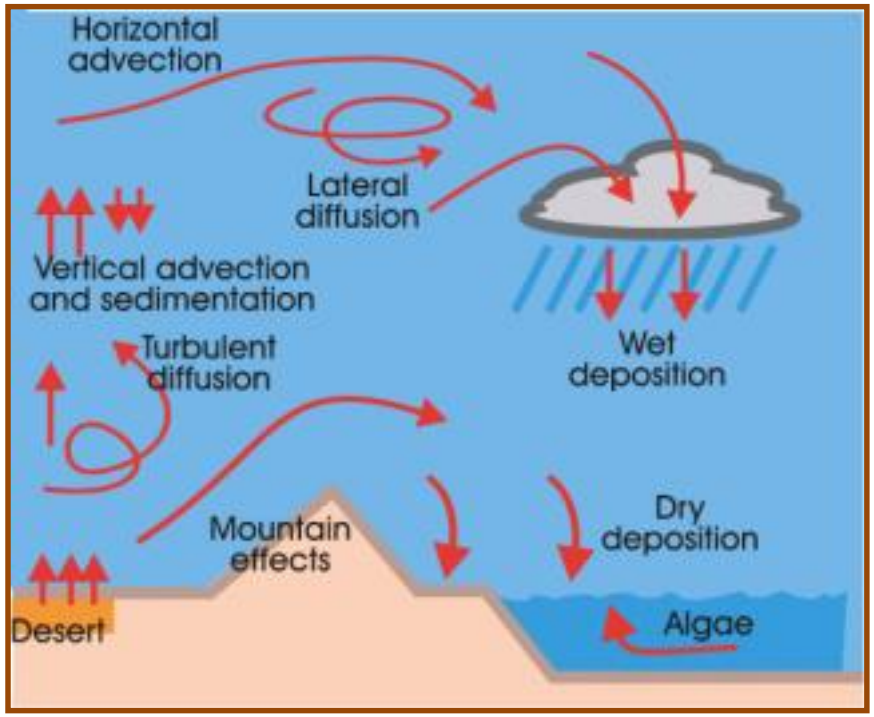
AEMet Agencia Estatal de Meteorología
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación
World Meteorological Organization Weather • Climate • Water

Dust prediction models

NWP model	+	Equation of the dust cycle	=	Dust prediction model



- Emission
- Turbulent diffusion
- Transport
- Dry and wet deposition

- Interaction with radiation
- Interaction with cloud particles
- Atmospheric chemistry
- …

Dust prediction: main problems

- **Processes of very different scales**
- **Need for very precise wind prediction**
- **Lack of suitable observations for forecast evaluation and data assimilation**

Tegen et al. (1994)

$$F = \sum_i C_i u^2 (u - 6.5)$$

Marticorena et al. (1997)

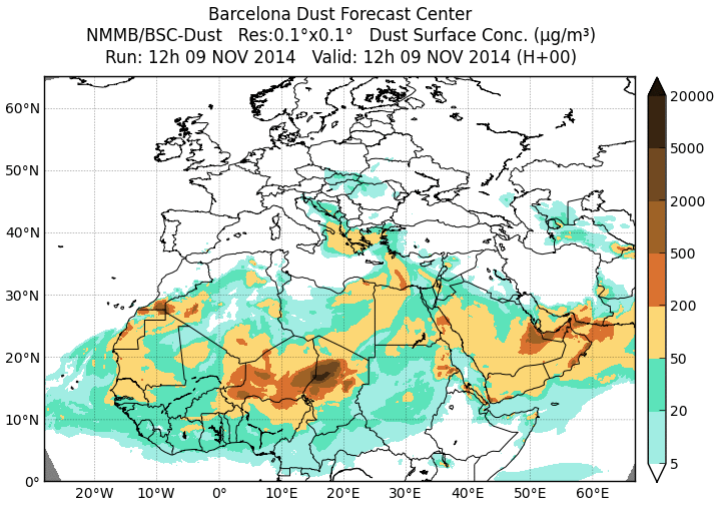
$$F = \propto \frac{\rho}{g} u_*^3 \sum_i s_i \left(1 + \frac{u_{*tri}}{u_*}\right)\left(1 - \frac{u_{*tri}^2}{u_*^2}\right)$$

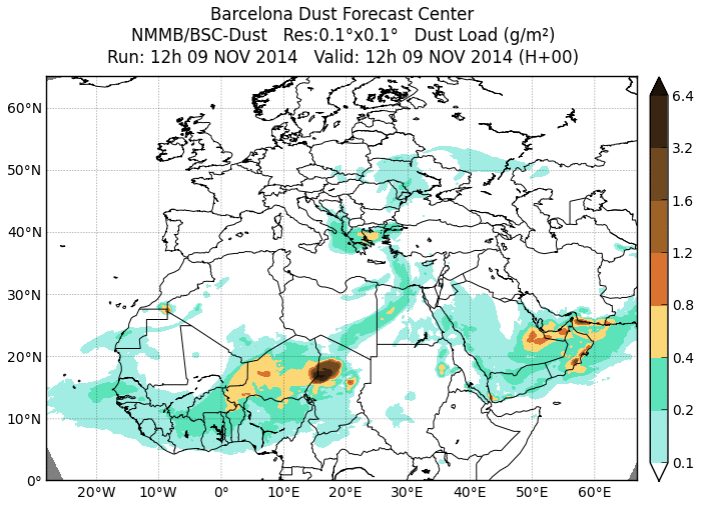
Ginoux et al. (2001)

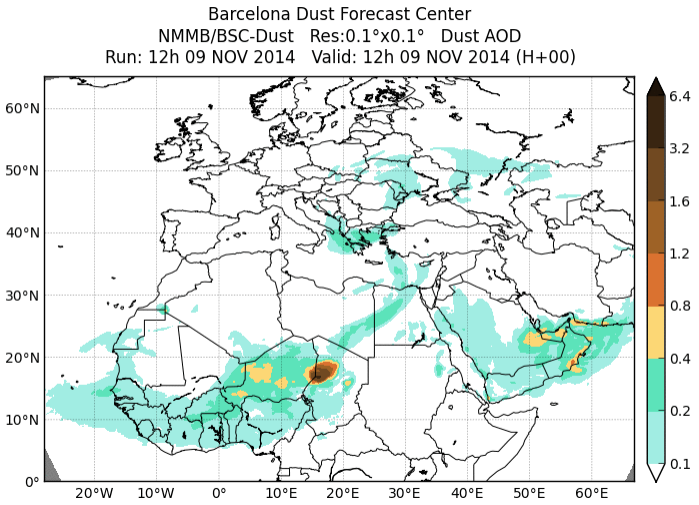
$$F = CS \sum_i u^2 s_i w_0 (u - u_{tri})$$

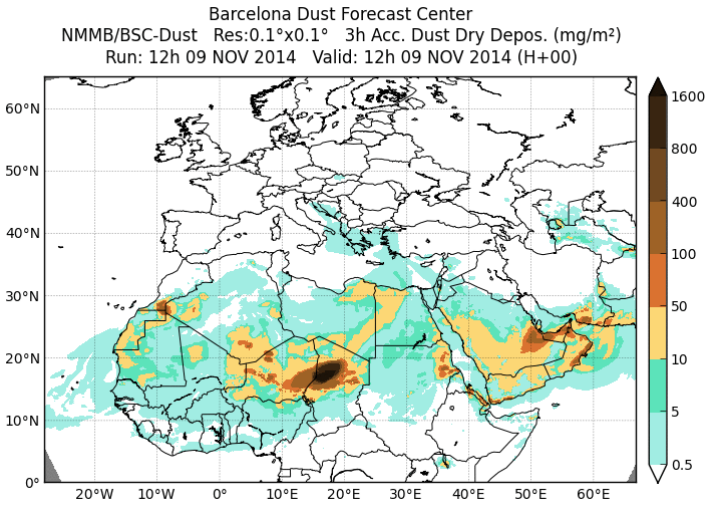
Prediction of atmospheric dust

Forecast products







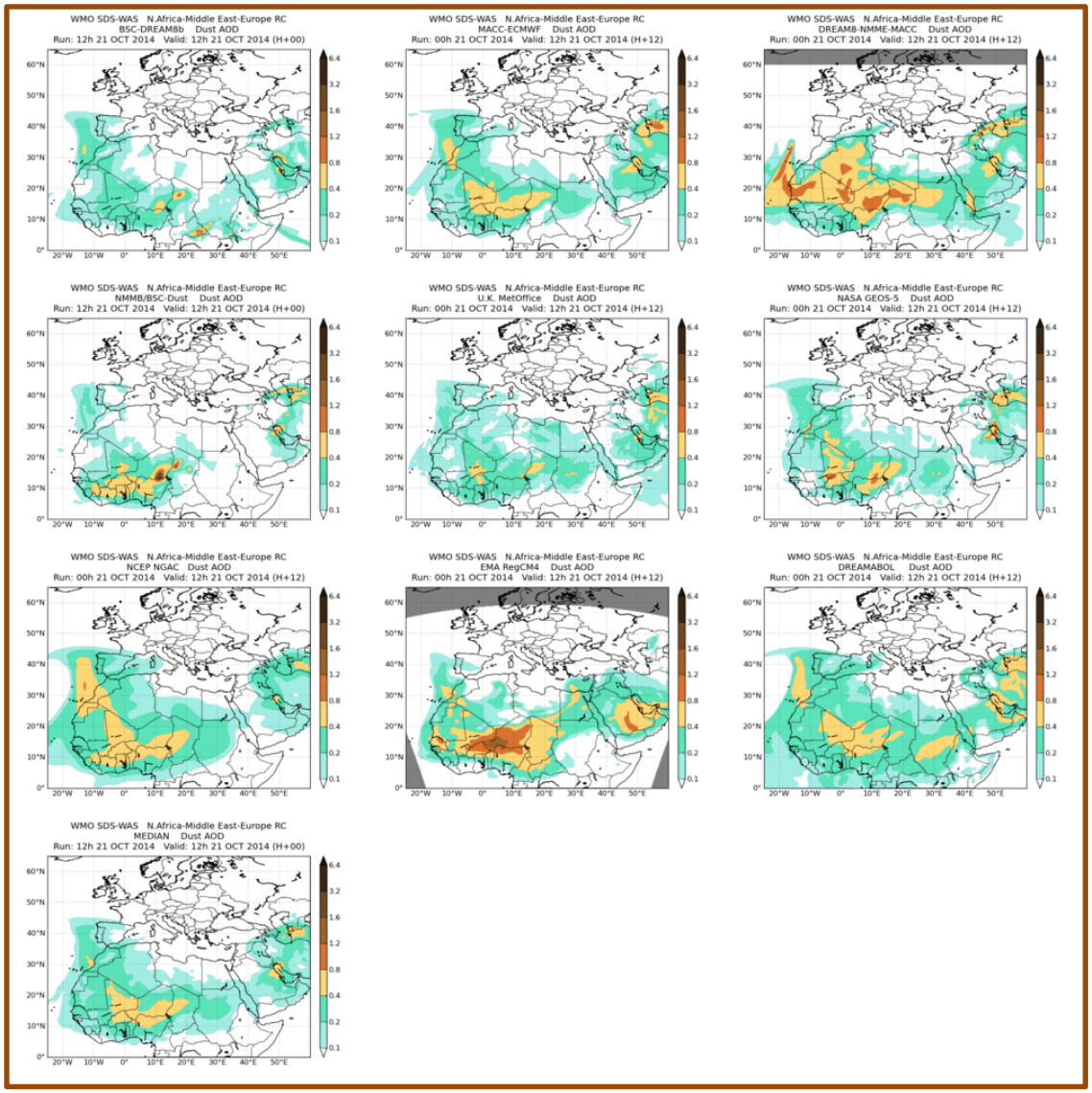


BARCELONA DUST FORECAST CENTER

WMO SDS-WAS || NA-ME-E Regional Center

Prediction of atmospheric dust

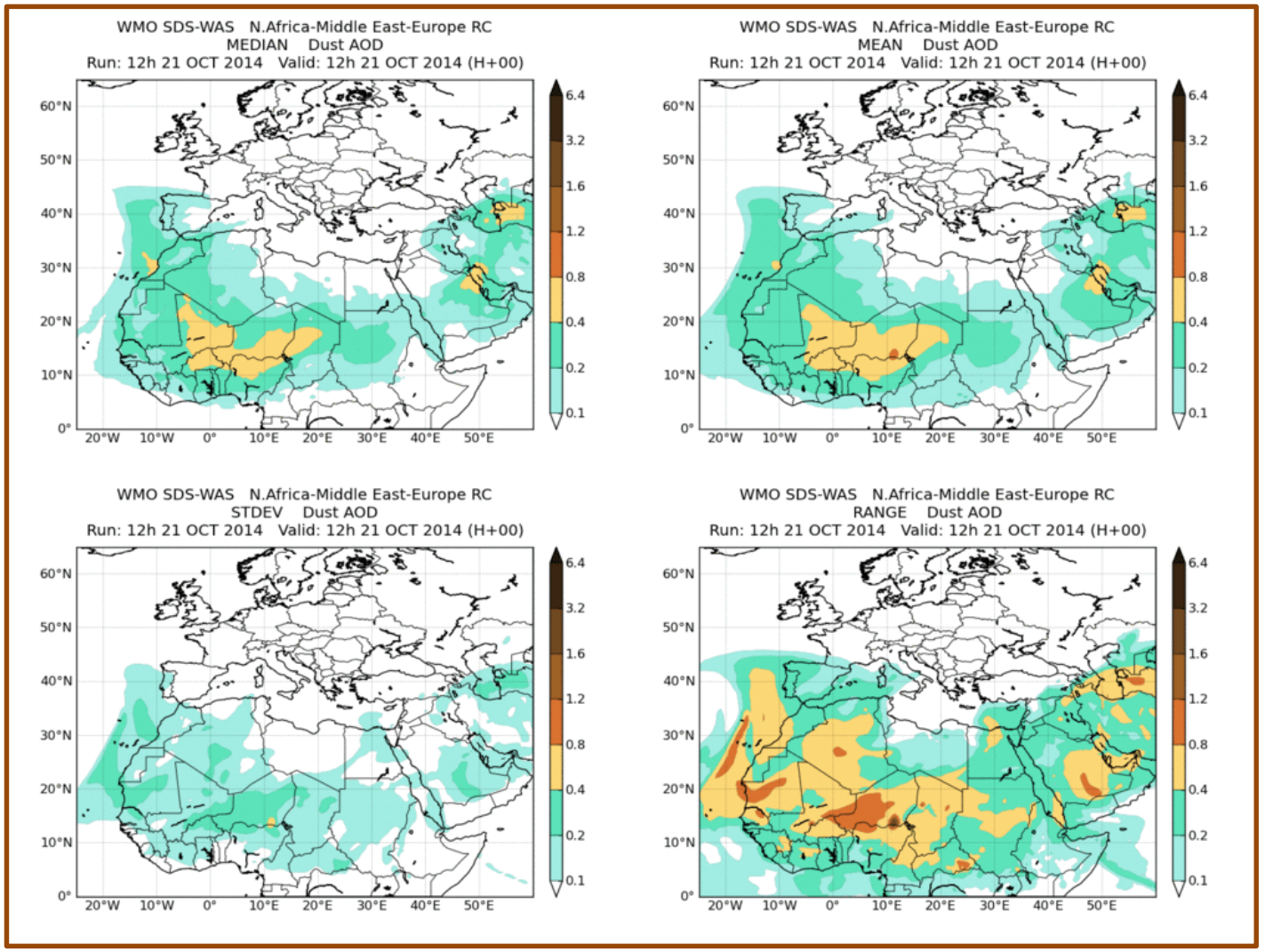
Dust optical depth at 550 nm



Dust optical Depth 550 nm. Models runtime: 21 Oct 2014

Prediction of atmospheric dust

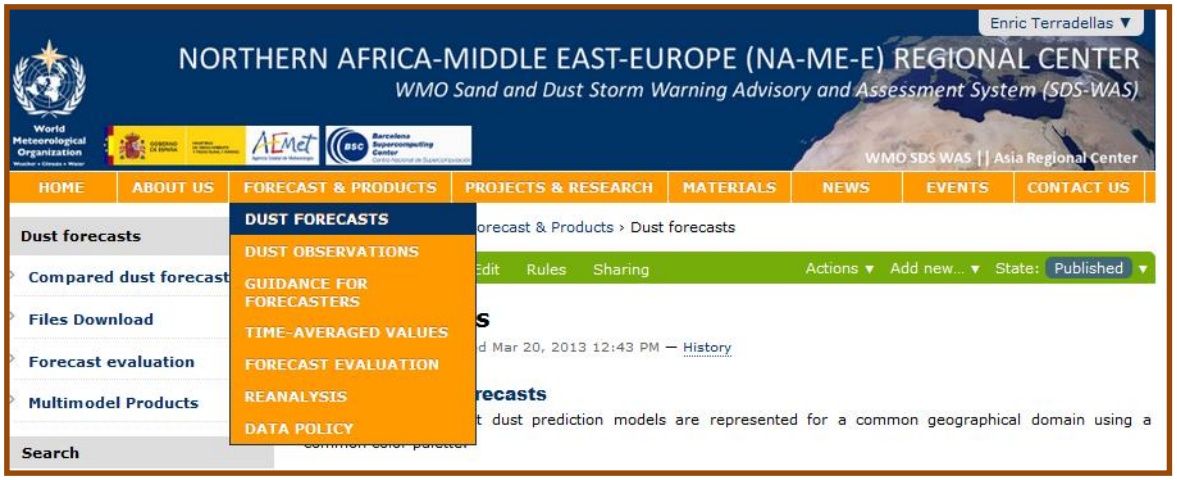
Multi-model products



Dust optical Depth 550 nm. Models runtime: 21 Oct 2014

Prediction of atmospheric dust

Download of numerical forecasts



Sfc. Concentración Dust AOD 550 µm

BSC-DREAM8b v2.0	DOWNLOAD FILES	Model website	Barcelona Supercomputing Center
MACC-ECMWF	DOWNLOAD FILES	Model website	macc
DREAM-NMME-MACC	DOWNLOAD FILES	Model website	SEEVCCC
NMMB/BSC-Dust	DOWNLOAD FILES	Model website	Barcelona Supercomputing Center
NASA-GEOS-5	DOWNLOAD FILES	Model website	NASA
NCEP-NGAC	DOWNLOAD FILES	Model website	NCEP
Multimodel MEDIAN	DOWNLOAD FILES	Model website	

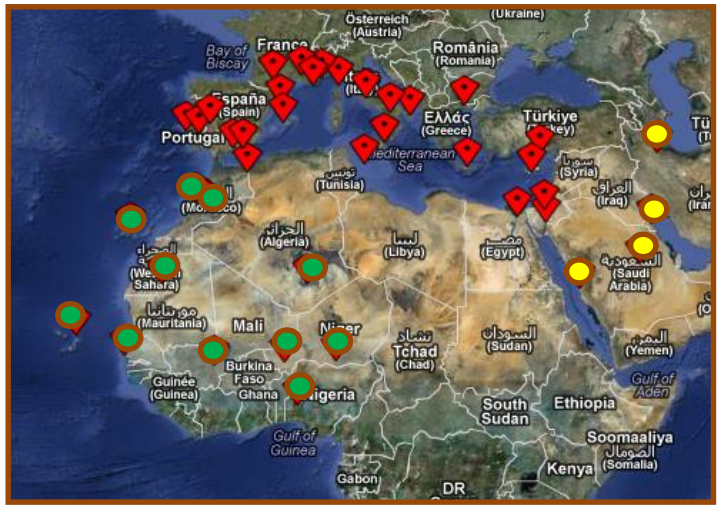
netCDF format

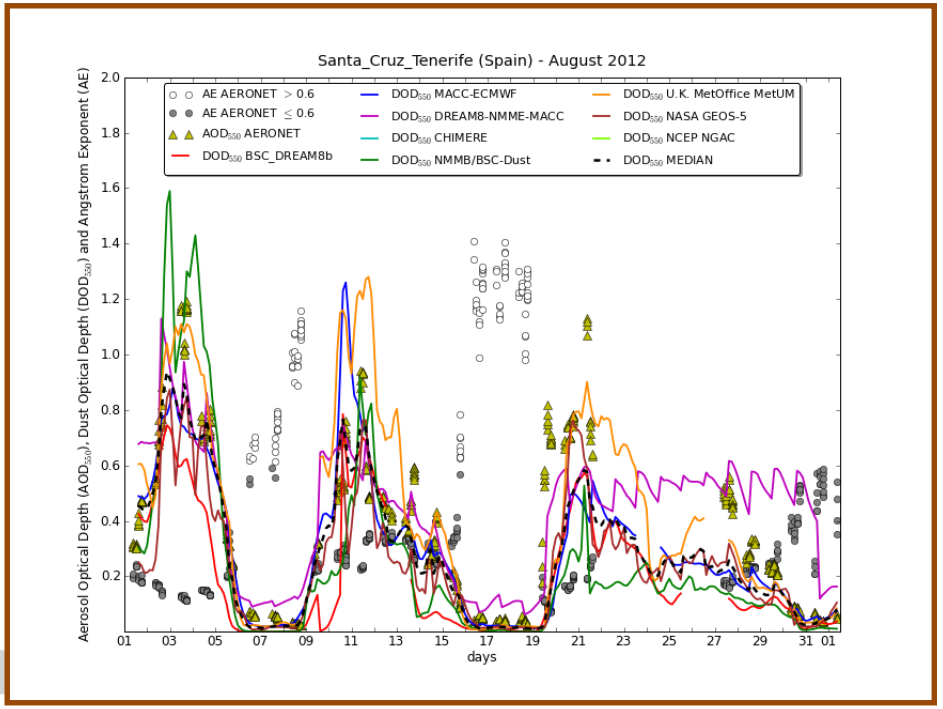
netCDF UCAR unidata

Title	Size	Modified
latest - *(download all)*	4.0 kB	Apr 18, 2013 09:00 PM
2013 - *(download all)*	4.0 kB	Apr 01, 2013 09:00 PM
2012 - *(download all)*	4.0 kB	Apr 08, 2013 04:30 PM

Prediction of atmospheric dust

Forecast evaluation with AERONET data





Model evaluation metrics. Seasonal scores

by Francesco Benincasa — last modified Mar 25, 2013 05:26 PM — History

Date: - Select Year - - Select Season -

Dec 2012 - Feb 2013. Dust Optical Depth.
Threshold Angstrom Exponent = 0.600

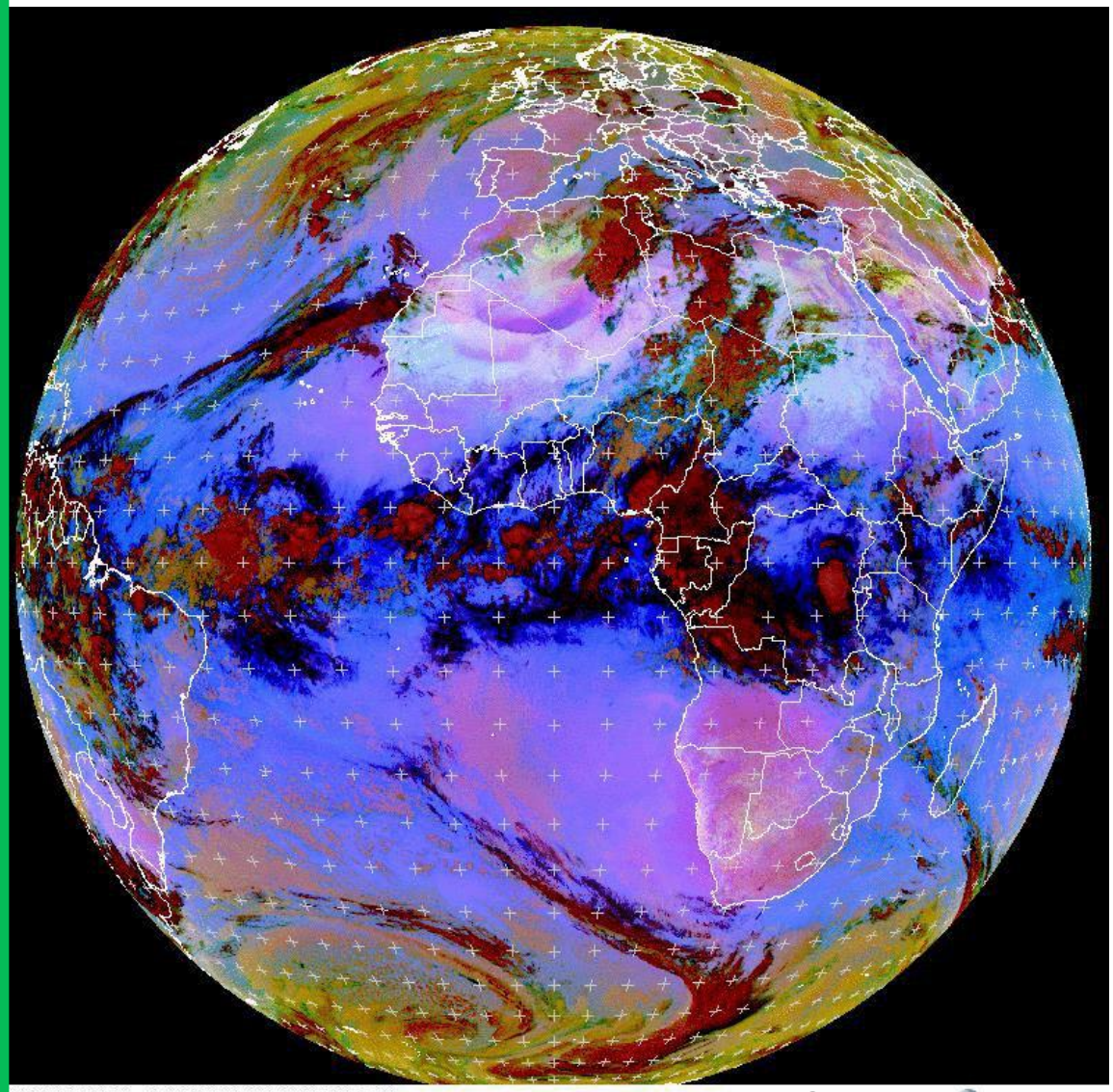
BIAS

	BSC_ DREAM8b	MACC-ECMWF	DREAM8-NMME-MACC	NMMB/BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	MEDIAN
Sahel/Sahara show stations	-0.18	-0.14	-0.14	-0.09	0.00	-0.08	-0.03	-0.11
Middle East show stations	-0.12	-0.13	-0.04	-0.22	-0.00	-0.15	-0.14	-0.13
Mediterranean show stations	-0.13	-0.14	-0.12	-0.15	-0.09	-0.14	-0.11	-0.13
TOTAL	-0.16	-0.14	-0.13	-0.12	-0.03	-0.11	-0.07	-0.12

- Bias
- RMSE
- Correlation coefficient
- FGE

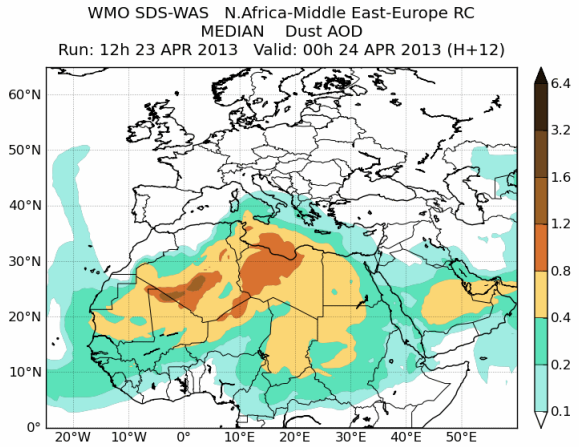
Monthly
Seasonal
Yearly

Forecast evaluation with satellite prods.



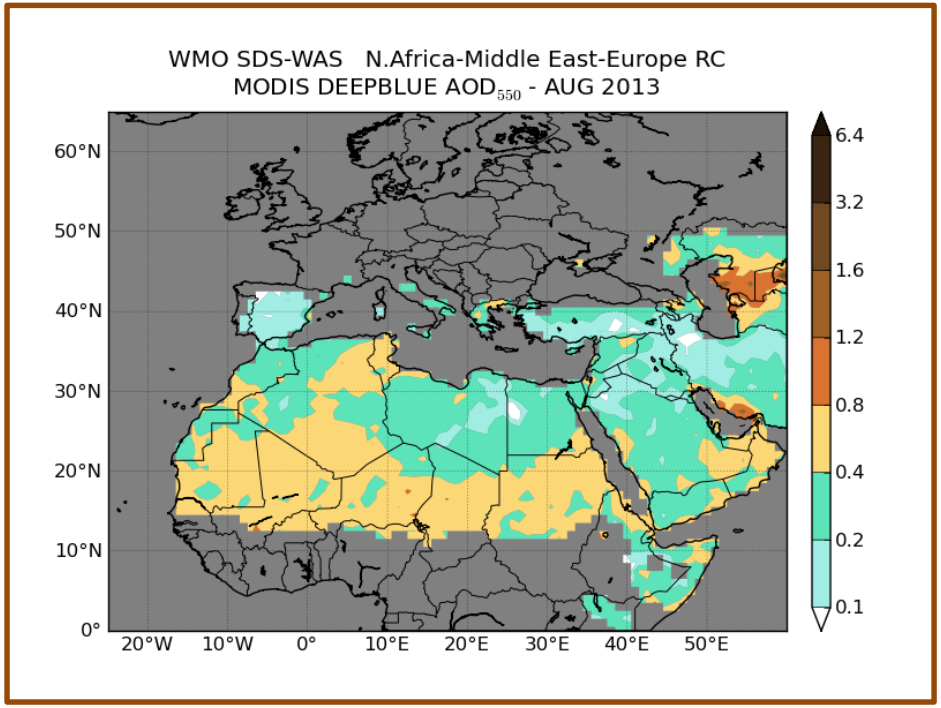
EUMETSAT

24 April 2013



Prediction of atmospheric dust

Evaluation with MODIS Deep Blue

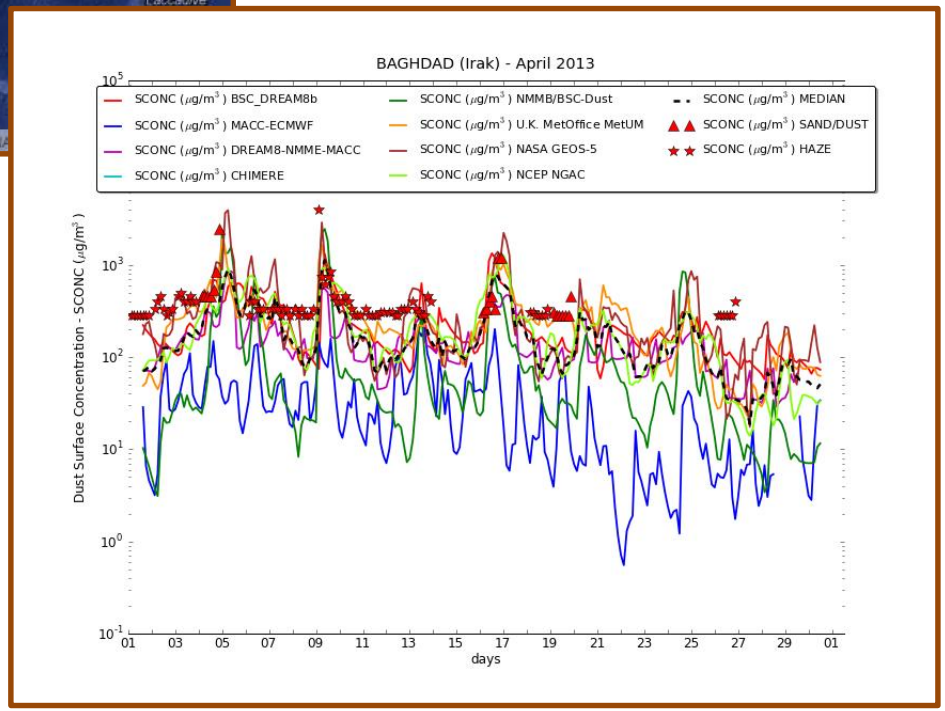


	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	**-0.17**	**0.31**	**0.28**	**0.96**	**42618**
NMMB/BSC-Dust	**-0.20**	**0.33**	**0.29**	**1.05**	**41049**
NCEP NGAC	**-0.06**	**0.29**	**0.32**	**0.64**	**42664**

Prediction of atmospheric dust

Evaluation with visibility

PM10 = 1339.84 $V^{-0.67}$
Ben Mohamed et al. (1992)



BAGHDAD, iraq
April 2013

Prediction of atmospheric dust

LIDAR – models comparison

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

BSC-DREAM8B_v2
NMMB-BSC/Dust

SEEVCCC

DREAM8-NMME-MACC

Consiglio Nazionale delle Ricerche

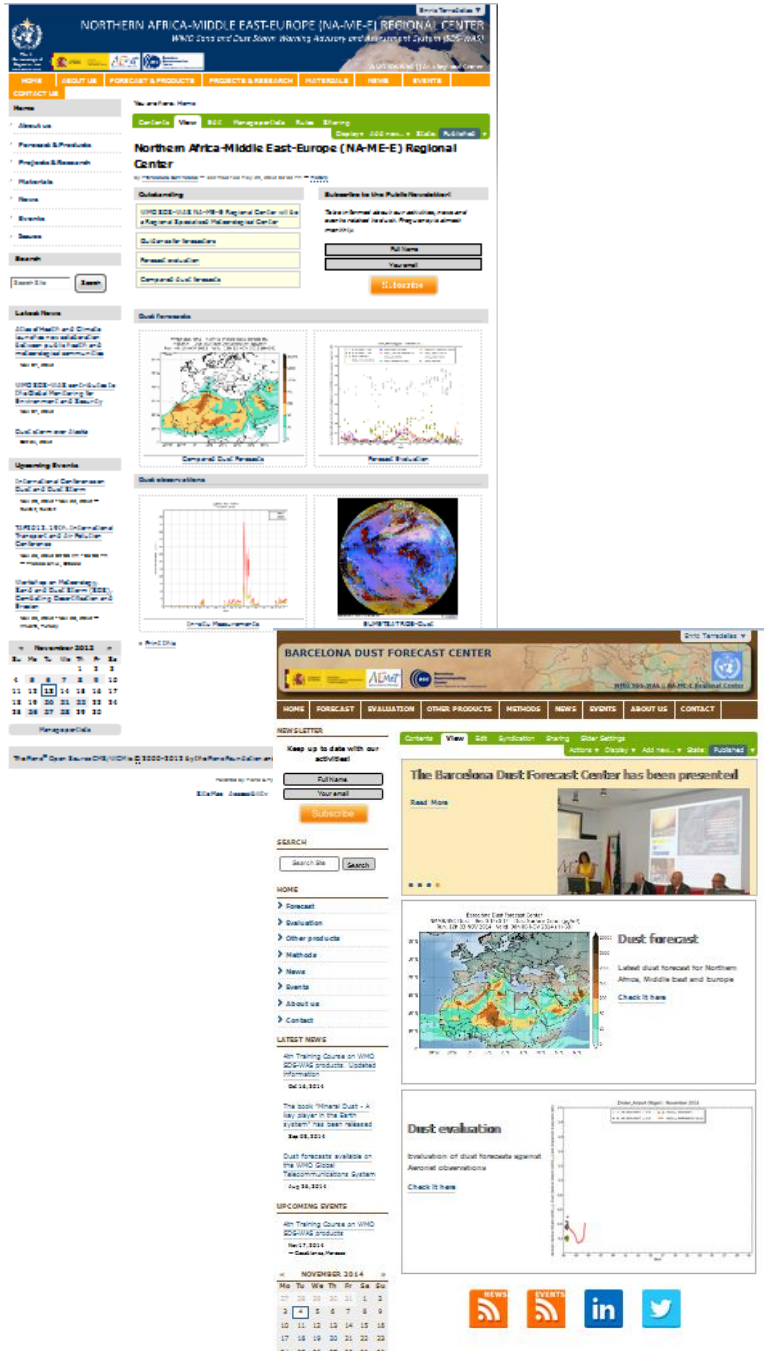
BOLCHEM

60 – 80 dust cases for the period Jan 2011 – Jun 2013

Capacity building

- 8-12 Nov 2010: Training Week on Satellite Meteorology. Barcelona, Spain
- 13 Nov 2010: Lectures on Atmospheric Mineral Dust and its Impact on Human Health, Environment and Economy. Barcelona, Spain
- 15-19 Nov 2010 Training Week on WMO SDS-WAS products. Barcelona, Spain
- 22-26 Feb 2011: Training on Meteorological Services, SDS Forecast and Early Warning System. Istanbul, Turkey
- 21-25 Nov 2011: 2nd Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust). Antalya, Turkey
- 5-9 Nov 2012: II Lectures on Atmospheric Mineral Dust. Barcelona, Spain
- 19-23 Nov 2012: Cours sur l'utilisation des produits satellitaires aux applications agrometeorologiques, Niamey, Niger
- 26-28 Nov 2012: Workshop on Meteorology, Sand and Dust Storm (SDS), Combating Desertification and Erosion. Ankara, Turkey
- *10-14 Jun 2013:* Training Course on the Use of Satellite Products for Agrometeorological Applications, Accra, Ghana
- 28-31 Oct 2013: Workshop on Meteorology, Sand and Dust Storm (SDS), Combating Desertification and Erosion, Istanbul, Turkey
- 8-12 Dec 2013: 3rd Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust), Muscat, Oman
- 15-16 Dec 2013: McIDAS-V Tutorial with focus on atmospheric dust cases, Muscat, Oman
- 5-9 May 2014: Cours sur l'utilisation des produits satellitaires aux applications agrométéorologiques , Ouagadougou, burkina Faso
- 17-20 Nov 2014: 4th Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust). Casablanca, Morocco

Thanks for your attention



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